PB83-258665

Proceedings: Symposium on Iron and Steel Pollution Abatement Technology for 1982 Held at Pittsburgh, Pennsylvania, on November 16-18, 1982

Research Triangle Inst.
Research Triangle Park, NC

Prepared for

Industrial Environmental Research Lab.
Research Triangle Park, NC

Sep 83

U.S. Department of Commerce
National Technical Information Service
NTIS

PB83-258665

EPA-600/9-83-016
September 1983

Proceedings: Symposium on Iron and Steel Pollution Abatement Technology for 1982 (Pittsburgh, PA, 11/16-11/18/82)

Franklin A. Ayer, Compiler

Research Triangle Institute
P. O. Box 12194
Research Triangle Park, NC 27709

EPA Contract No. 68-02-3152
Task No. 12

AISI Contract No., Letter May 24, 1982

EPA Project Officer: Robert C. McCrillis

Industrial Environmental Research Laboratory
Research Triangle Park, NC 27711

AISI Project Manager: Earle F. Young, Jr.

American Iron and Steel Institute
Washington, DC 20036

Prepared for

U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Research and Development
Washington, DC 20460

and

American Iron and Steel Institute
Washington, DC 20036

REPRODUCED BY
NATIONAL TECHNICAL
INFORMATION SERVICE
U.S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA. 22161

TECHNICAL REPORT DATA

(Please read Instructions on the reverse before completing)

1. REPORT NO. EPA-600/9-83-016	2.	3. RECIPIENT'S ACCESSION NO. PB83 258665
4. TITLE AND SUBTITLE Proceedings: Symposium on Iron and Steel Pollution Abatement Technology for 1982		5. REPORT DATE September 1983
		6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) Franklin A. Ayer, Compiler		8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS Research Triangle Institute P.O. Box 12194 Research Triangle Park, North Carolina 27709		10. PROGRAM ELEMENT NO.
		11. CONTRACT/GRANT NO. 68-02-3152, Task 12
12. SPONSORING AGENCY NAME AND ADDRESS **EPA, Office of Research and Development*** **Industrial Environmental Research Laboratory** **Research Triangle Park, NC 27711**		13. TYPE OF REPORT AND PERIOD COVERED Proceedings; 11/16-18/82
		14. SPONSORING AGENCY CODE EPA/600/13

15. SUPPLEMENTARY NOTES IERL-RTP project officer is Robert C. McCrillis, Mail Drop 63, 919/541-2733. (*) Cosponsored by American Iron and Steel Institute, Washington, DC, 20036. EPA-600/9-82-021 is the proceedings for the 1981 symposium.

16. ABSTRACT The proceedings document presentations at the Symposium on Iron and Steel Pollution Abatement Technology for 1982, the fourth in this series, held in Pittsburgh on November 16-18, 1982. It provided a forum for the exchange of information on technological problems related to multimedia pollution control in the iron and steel industry. American and international representatives from industry, academia, the research community, public interest organizations, and Federal and state governments participated. The opening session dealt with cost reduction, rational decision-making in technological development, alternatives to confrontation between industry and environmentalists, a geographic approach to integrated environmental management, and environmental trade-offs. Subsequent sessions dealt with other aspects of solid waste, air, and water pollution abatement related to the industry. In all, 186 people participated in the symposium.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Pollution	Pollution Control	13B
Iron and Steel Industry	Stationary Sources	05C, 11F

18. DISTRIBUTION STATEMENT **Release to Public**	19. SECURITY CLASS *(This Report)* Unclassified	21. NO. OF PAGES 392
	20. SECURITY CLASS *(This page)* Unclassified	22. PRICE

EPA Form 2220-1 (9-73)

NOTICE

This document has been reviewed in accordance with U.S. Environmental Protection Agency policy and approved for publication. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

PREFACE

These proceedings for the "Symposium on Iron and Steel Pollution Abatement Technology for 1982" constitute the final report submitted by the Research Triangle Institute to the Industrial Environmental Research Laboratory, U.S. Environmental Protection Agency (IERL-EPA), Research Triangle Park, NC, in fulfillment of EPA Contract 68-02-3152, Task 12, and to the American Iron and Steel Institute (AISI), 1000 16th Street, N.W., Washington, DC, in fulfillment of AISI letter of agreement. The symposium was conducted at The William Penn Hotel, Pittsburgh, PA, on November 16-18, 1982.

The opening session included addresses on cost reduction of air pollution in the iron and steel industry, the need for rational decision making in technology development, an environmentalist's view as to alternatives for pollution control, and a geographic approach to integrated environmental management. A panel discussion by speakers in the opening session on Environmental Trade-offs followed. Four subsequent sessions were conducted on multimedia, solid waste, air, and water pollution abatement technology. Technical presentations and discussions by participants from industry, academia, research organizations, government agencies, and public interest groups were made.

Mr. Robert C. McCrillis, Mechanical Engineer, Industrial Environmental Research Laboratory, U.S. Environmental Protection Agency, Research Triangle Park, NC, and Mr. Earle F. Young, Jr., Vice President, Energy and Environment, American Iron and Steel Institute, Washington, DC, served as Project Officers and General Chairmen for the symposium.

TABLE OF CONTENTS

Page

OPENING SESSION. 1
Richard D. Stern, Chairman

Statement of Symposium Objectives. 2
Robert C. McCrillis

Reducing the Cost of Air Pollution Control in the Iron and Steel Industry 3
Peter N. Bibko and David L. Arnold (Presented by Stanley L. Laskowski)

Rational Decisionmaking in Technology Development. 9
William L. West

Environmentalists vs. the Steel Producers; Are There Alternatives to Confrontation?. 15
Walter I. Goldburg

The Geographic Approach to Integrated Environmental Management 21
Michael R. Alford

Panel: Environmental Trade-offs 32
Michael R. Alford, Chairman
Stanley L. Laskowski, William L. West, and Walter I. Goldburg, Panel Members

SESSION 1: MULTIMEDIA POLLUTION ABATEMENT 33
Michael R. Alford and Joseph G. Crist, Chairmen

Mission and Research Programs of the Industrial Waste Elimination Research Center. 34
James W. Patterson

Chromium Removal Mechanisms for Waste Management of a Specialty Steel Mill 49
Virginia M. Cusano and Robert H. Wills, Jr.*

Landfilling Solid Wastes from Specialty Steel Production on a Solvay Process Wastebed. 62
J. A. Hagarman,* R. W. Klippel, and R. H. Wills, Jr.

*Denotes speaker

Preceding page blank

Page

Particulate and Particle Size Data for Clean and Contaminated Quench Water Usage - Dofasco No. 1 Wet Coke Quench Tower 73
John D. Jeffery

SESSION 2: SOLID WASTE POLLUTION ABATEMENT. 92
Penelope Hansen and David G. Boltz, Chairmen

Groundwater Monitoring Strategies for Steel Industry Residue Disposal Operations. 93
Andrew P. Pajak* and David W. Hupe

Recovery of Metallic Values from Electric Arc Furnace Steelmaking Dusts. 105
E. Radha Krishnan* and William F. Kemner

Mill Scale De-Oiling by Critical-Fluid Extraction. 122
Thomas J. Cody, Jr., Richard P. de Filippi,* and Christopher P. Eppig

SESSION 3: AIR POLLUTION ABATEMENT. 135
Murray Greenfield and James R. Zwikl, Chairmen

Determination of the Decay in Control Efficiency of Chemical Dust Suppressants on Unpaved Roads 136
Thomas Cuscino, Jr.,* Gregory E. Muleski, and Chatten Cowherd, Jr.

The Effect of Dust Control Measures in a Dutch Iron and Steel Works. 149
Cornelis A. Aronds

Fugitive Dust Emissions from Roads in Iron and Steel Mills: Compilation of Results and Use Under EPA's Emission Trading Policy 166
L. L. Simmons,* C. L. Norton, and M. J. DeBiase

A Comparison of Alternative Coke Pushing Emission Control Systems. . .182
Daniel J. Metzger* and Nona L. Hancock

The Precision of Visual Emission Observations Within An Integrated Steel Works 190
D. E. Splitstone* and J. Y. Lin

The Relationship Between Visual-Emission Observations and Continuous-Emission Monitor Measurements of Coke-Battery Stacks. . . .201
D. E. Splitstone* and B. C. Erickson

*Denotes speaker

Page

Benzene Emissions Sources and Emissions Control at Coke By-Product Plants 218
Leslie L. Beck,* C. Clark Allen, and David W. Coy

Blast Furnace Casthouse Emission Control Without Evacuation. 232
S. Vajda

Critical Review of Electric Arc Furnace Particulate Emissions Control Technology 241
Jaffer Mohiuddin

SESSION 4: WATER POLLUTION ABATEMENT. 253
John S. Ruppersberger and S. Charles Caruso, Chairmen

Development of a Rotating-Biological-Contactor for the Removal of Ammonia from Blast-Furnace Recycle-Water Blowdown 254
K. C. Krupinski* and P. H. Damon

Blast Furnace-Recycle System Side Stream Softening Summary of Full Scale Trial 272
Leonard D. Wisniewski* and Richard L. Nemeth

Costs of Pre-Treatment of Coke-Plant Effluents 286
J. Ganczarczyk and M. Kelleher*

Treatment of Coke Plant Wastewater With or Without Blast Furnace Blowdown Water in a Two-Stage Biological Fluidized Bed System 300
S. G. Nutt,* H. Melcer, I. J. Marvan, and P. M. Sutton

Physical/Chemical Treatment of Coke Plant Wastewaters. 316
James R. Zwikl, Nicholas S. Buchko,* and David R. Junkins

Nitrification Kinetics as Influenced by Coke Plant Wastewaters 346
Ronald D. Neufeld* and Jeffrey H. Greenfield

Effective Operation and Maintenance Practices for Wastewater Treatment Systems in the Iron and Steel Industry 357
William F. Kemner and Richard T. Price*

APPENDIX: ATTENDEES 379

*Denotes speaker

BEGIN FIRST LINE OF TEXT HERE
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD, BEGIN SECTIONS HERE
6-1/2"
9-1/8"

OPENING SESSION

Chairman: Richard D. Stern
Industrial Environmental Research Laboratory
U.S. Environmental Protection Agency
Research Triangle Park, NC

BEGIN LAST LINE OF TEXT
3/8"
BOTTOM OF IMAGE AREA, OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS

EPA Form 2350-4 (4-80)
(PREVIOUSLY CIN. EPA FORM 257)
TYPING GUIDE SHEET

STATEMENT OF SYMPOSIUM OBJECTIVES

by: Robert C. McCrillis
Industrial Environmental Research Laboratory
U.S. Environmental Protection Agency
Research Triangle Park, NC

Today marks a historic occasion! Inspite of budget cuts, steel production at only 40% of capacity and an accompanying worldwide recession, we are here. I cannot think of a more appropriate location to hold a symposium devoted to iron and steel environmental technology than Pittsburgh, the birthplace of the modern steel industry and a leader in the quest for ameliorating its environmental impacts. Of special significance is that this, the fourth Symposium on Iron and Steel Pollution Abatement Technology, is the first of this series to be cosponsored by the American Iron and Steel Institute. I believe the fact that we are here today attests to the high level of interest and the strong commitment of both EPA and AISI towards attaining this nation's environmental goals. That all of you are here confirms my belief. I am also pleased that, for the first time, the Air Pollution Control Association is a formal participant, helping primarily in the organization of the air session.

Although there has been a broadening of the sponsorship, there has been no change in the symposium's objectives. We--EPA, AISI, and APCA--are as one in our commitment to present to you a program which will focus your attention on technological solutions to environmental problems. You will hear about innovative technology and ideas, improvements in design and operating procedures and the economics of pollution control. The speakers selected represent a wide cross section of industry, government, and contractor viewpoints.

The opening session, with its emphasis on multimedia trade-offs, leads into the Multimedia Pollution Abatement Session, followed by sessions focusing on solid waste, air pollution, and water pollution. Highlighting the multimedia aspect--new this year--reflects the need to view environmental control in its entirety. Controlling discharges to one media without consideration of impacts on other media may only result in moving the problem, not solving it. Cost-effective minimization of total environmental impact should be the ultimate goal.

This symposium is an open forum, an assembly for the discussion of questions. I want to stress the phrase discussion of questions. No one holds a monopoly of knowledge. If a speaker raises a question in your mind, by all means ask it. Only through your active participation can you hope to achieve the full measure of benefit.

I welcome you here and hope you benefit from and enjoy the next three days.

This paper has been reviewed in accordance with the U.S. Environmental Protection Agency's peer and administrative review policies and approved for presentation and publication.

REDUCING THE COST OF AIR POLLUTION CONTROL IN THE IRON AND STEEL INDUSTRY

Peter N. Bibko
Regional Administrator
U.S. Environmental Protection Agency - Region III
6th & Walnut Streets
Philadelphia, PA 19106

David L. Arnold
Environmental Engineer
U.S. Environmental Protection Agency - Region III
6th & Walnut Streets
Philadelphia, PA 19106

ABSTRACT

The goal of the Environmental Protection Agency's regulatory reform efforts is to facilitate the use of more effective, less costly control measures while assuring a cleaner environment. The reforms in the air programs are known as Emissions Trading and include the bubble policy, offset policy, and emission reduction banking. Of these reforms, the bubble policy has become the most well known and publicized program. At a time of rising control costs and shrinking resources, the policy can speed both economic growth and continued progress toward clean air. For the iron and steel industry, the policy offers increased flexibility, less government intrusion in the corporate planning process, and savings of millions of dollars in annual control costs. For the environmental community, it should result in more air quality progress than additional direct regulation. For the economic development community, it can facilitate the revitalization of existing plants. This paper briefly discusses what the policy is and how it can be used; and describes three bubble projects which were developed by iron and steel companies in Region III.

THE BUBBLE POLICY

INTRODUCTION

Since 1979, the Environmental Protection Agency has implemented a major air pollution reform known as the "Bubble Policy". This policy provides industry the flexibility to treat total plant emissions as though they were emerging from an imaginary enclosure, or bubble, covering all the relevant sources of air pollution. It is based on the belief that EPA and the States should be primarily concerned with a plant's overall impact on air quality, rather than how the plant meets environmental regulations. Unlike the traditional regulatory approach, which sets specific limitations for every emission point, the bubble policy allows plants to tighten controls on a pollutant where control costs are low in exchange for relaxing controls equally where costs are high. A firm may redistribute emissions on a least-cost basis across all relevant point sources of emissions, with the new emission limits becoming legally binding and enforceable. On April 7, 1982, EPA announced the new "Emissions Trading Policy" (47FR15076) which replaces the original bubble policy of 1979 and allows broader use of the bubble to achieve compliance in industrialized urban areas. Specifically, the new policy made the following major changes:

--Allows states to adopt generic trading rules for particulates and sulfur dioxide, in addition to volatile organic compound emissions. Many trades under these rules can be approved by states without overlapping EPA review.

--Streamlines air quality modeling requirements to make it easier for states and industry to evaluate the ambient impact of proposed trades.

--Extends use of the bubble to areas lacking approved demonstrations of attainment, speeding compliance in these areas consistent with prompt progress towards healthy air.

--Expands opportunities for firms to use bubbles to meet stringent RACT control requirements in industrial areas.

--Allows sources to use the bubble to achieve rapid compliance.

--Removes or reduces other unnecessary constraints affecting automotive, paper, steel, oil, chemical and other basic industries.

These and other changes are more fully explained in EPA's Emissions Trading Technical Issues Document located in the Federal Register at 47FR15079 (April 7, 1982).

USING THE BUBBLE

The Policy Statement of April 7, 1982 sets out the basic principles and requirements for the use of a bubble or alternative emission reduction plan by an interested firm. Rather than repeat the full text of the policy, the basic requirements are listed below in a summarized form. Please refer to the full text for additional information.

Pollutants And Air Quality

Bubble trades must involve the same criteria pollutant. That is, only reductions of particulates can be substituted for increases of particulates, VOC's for VOC's, etc. In addition, hazardous pollutants can not increase. Bubble trades must also be equivalent in ambient air quality impact. That is, emissions trades must show no significant impact on air quality. A bubble trade must also never cause a new violation of an ambient air quality standard. To simplify demonstrations of equivalency, EPA has authorized the use of three tiered air quality analysis. A description of each type of analysis is contained in the discussions of case examples in the sections to follow.

BEGIN FIRST LINE OF TEXT HERE
CENTER OF PAGE
TOP OF IMAGE AREA

Enforcement And Technology Based Requirements

Bubble emission limits must be as enforceable as current regulatory emission limits. The emission limits can be in the form of a state regulation, permit condition or consent order. Bubble trades cannot be used to meet applicable technology-based requirements, i.e. new source performance standards (NSPS), best available control technology (BACT) requirements in PSD areas, or lowest achievable emission rate (LAER) requirements in nonattainment areas.

DROPPED HEAD; BEGIN SECTIONS HERE

Using the above principles, the three iron and steel companies discussed in this paper have shown that a firm can develop a less costly method of pollution control while assuring a cleaner environment.

CASE EXAMPLES

Company A

The company operates a coke and iron works. The plant began development of its bubble plan shortly after the original bubble policy was published (December 1979). Because the company was subject to emission control requirements of a federal consent decree, the firm was faced with significant expenditures for air pollution control. Specifically, the company was required to install additional particulate emission controls on its blast furnace casthouse. Therefore, the plant focused its efforts on a bubble plan that would eliminate the need for the casthouse controls yet still provide for an air quality improvement. The company proposed to control fugitive particulate emissions from in-plant roads and parking areas using vacuum sweepers on paved areas and a dust suppressant on unpaved areas. While the proposal initially seemed to be a sound alternative, a major roadblock remained. The original bubble policy (1979) prohibited the use of an alternative emission reduction plan in a nonattainment area without an EPA approved demonstration of attainment. The area in and around the plant was classified nonattainment for particulate (TSP) and had no attainment plan. As a result, the company embarked on developing a comprehensive plan that would not only support the bubble proposal but would also bring the area into attainment with the primary and secondary TSP standards by 1982.

The air quality analysis, submitted with the company's plan, consisted of diffusion modeling using emission rates for the base year (1979), for the existing SIP - approved regulations in 1982, and for the alternative plan. Existing data on ambient levels of TSP were available from three monitors operated by the local control agency. Four additional monitors were installed and operated in areas of expected high concentrations which were predicted by a preliminary model run. This data base was used in order to test attainment strategies through further modeling. The modeling predicted no exceedances of the TSP standard for 1982 under the bubble plan. In order to demonstrate the effectiveness of the road dust controls in reducing

BEGIN LAST LINE OF TEXT
3/8"
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS

EPA Form 2350-4 (4-80)
(PREVIOUSLY CIN. EPA FORM 257)
TYPING GUIDE SHEET

ambient levels of TSP, a six month site specific monitoring analysis was conducted. This analysis included monitoring before and after a portion of the road controls were implemented. The results indicated a 70% reduction of emissions was achieved by controlling unpaved roads, while 80% control was achieved on the paved roads. In addition to quantitative sampling, samples of road dust and casthouse emissions were also taken for the purpose of determining particle size distribution. Results of this analysis indicated that particles emitted from the casthouse were similar in size to particles emitted from the roads. Specifically, an equal percentage of particles below 15 microns in diameter was found in road dust and casthouse emission samples. (Particles below this size are considered more detrimental to human health due to their respirability). The total reduction in particulate emissions from roads and parking areas amounted to 297 tons per year. This exceeds the TSP reductions that would have occured from the installation of fugitive blast furnace casthouse emission controls, 90 tons per year based on EPA estimates, providing for an overall reduction in TSP emissions of 207 tons per year and an environmentally beneficial trading ratio of 3.3:1.

To ensure compliance with the bubble plan, sampling and recordkeeping requirements, as well as ambient monitoring requirements were incorporated into the State regulations. Because of the extensive and cooperative effort between the company, state, local and federal agencies, the plan received approval in 1981.

COMPANY B

The company operates integrated steel-making facilities in an industrialized urban area. Because of current business conditions, steel operations are at low levels. With this in mind, the company developed a bubble plan that would provide some cost savings during the present economic slowdown. The plan proposed, involved sulfur dioxide (SO_2) emission sources at two different plants. The plan allows emissions from two boilers to increase (by using higher sulfur coal) when the increase is offset by a reduction in emissions from the use of natural gas and reduced operations at open hearth furnaces, soaking pits and other miscellaneous sources at the two plants. This plan was developed in accordance with the new policy (April 1982).

To demonstrate that the bubble would result in an equivalent ambient air quality impact, a Level II analysis was conducted in accordance with EPA guidelines. A Level II analysis is required when the proposed bubble trade will result in no net increase in baseline emissions and the sources are not in the same immediate vicinity. Air dispersion modeling analyses were conducted using the proposed bubble emission rates and the base case emission rates. Results of the modeling indicated that no significant increase in air quality impact will occur at the receptor of maximum predicted impact. Base case emissions were determined by using an average of 1979-80 actual emissions. Total base emissions for the two plants

EPA Form 2350-4 (4-80)
(PREVIOUSLY CIN EPA FORM 287)
TYPING GUIDE SHEET

amounted to 7,614 tons per year. Under the bubble, total SO_2 emissions will be 3,342 tons per year or an overall net decrease of 4,272 tons per year, resulting in an emission reduction ratio of 2.2:1. Significant cost savings will also result by the use of lower cost high-sulfur coal. The plan will be enforced by incorporating specific emission limits and recordkeeping requirements into the State regulations. In order to expedite the approval of this plan, the local, State and federal agencies reviewed and processed this bubble concurrently. This resulted in the company receiving preliminary EPA approval six weeks after submittal.

Company C

The company also operates an integrated steel making facility. In order to comply with State particulate emission standards at their sinter plant, the firm faced the prospect of significant capital expenditures. The traditional options to control the sinter plant windbox were to either upgrade the existing electrostatic precepitators and or install additional new control equipment (both costly). As an alternative, the firm proposed to use the bubble concept. The plan would allow the particulate emissions from the two electrostatic precepitators controlling the sinter plant windbox, to exceed the currently applicable State regulations. This increase would be offset by improving the control efficiency of two baghouses which control particulate emissions from the discharge end of the plant and product screening operations. In addition, the company proposed to reduce emissions from an unpaved employee parking lot located at the plant. Total allowable emissions from the four emissions points at the sinter plant amounted to 139 pounds/hour. Under the bubble plan, the total emissions will be 136 pounds/hour resulting in a net decrease of 3 pounds/hour. In addition, controlling the parking lot will result in a reduction of 22 tons per year of particulate. This provides for an emission reduction ratio of approximately 1.1:1.

To demonstrate ambient air equivalence, the company justified the use of a Level I analysis (no air dispersion modeling) in accordance with the April 1982 policy. A Level I demonstration requires a source to show that the emission sources are in the same immediate vicinity; no increases in emissions will occur at the sources with the lower effective plume heights; and that there will be no net increase in overall emissions.

To ensure compliance with the plan, emission limits and testing requirements were established and incorporated into the State regulations. Again, to expedite the approval of this bubble, EPA agreed to process the plan concurrently with the State, thereby saving 4 to 6 months in processing time.

CONCLUSION

As can be seen from the above examples, emission trading and the bubble policy give plant managers the flexibility to use less costly equivalent

EPA Form 2350-4 (4-80)
[PREVIOUSLY CIN. EPA FORM 257]

TYPING GUIDE SHEET

alternative emission reductions in complying with regulations. While EPA does not know the size of potential cost savings, we do know that substantial savings *have already been realized through* bubbles, and their use is increasing. Bubbles currently under development in EPA, Region III could result in total cost savings as high as $145 million. In addition, the bubble cases discussed above resulted in net air quality improvements and faster implementation.

EPA is fully committed to the bubble concept as a better alternative to the traditional regulatory approach. With the cooperation and involvement of government, industry and the environmental community, bubble trades will not only reduce environmental compliance costs, but will produce real-world inprovements in air quality.

EPA Form 2350-4 (4-80)
(PREVIOUSLY CIN. EPA FORM ...)
TYPING GUIDE SHEET

The work described in this paper was not funded by the U.S. Environmental Protection Agency. The contents do not necessarily reflect the views of the Agency and no official endorsement should be inferred.

RATIONAL DECISIONMAKING IN TECHNOLOGY DEVELOPMENT

by: William L. West
Director, Environmental Control
Republic Steel Corporation
Cleveland, OH 44101

ABSTRACT

Environmental Control programs in the United States appear to be based upon an ever-increasing demand for more stringent technology. This trend should be examined for its necessity in relation to environmental goals and benefits. The underlying legislative and administrative policies should be modified when such modification can be accommodated without jeopardizing environmental goals.

EPA Form 2350-4 (4-80)
(PREVIOUSLY CIN. EPA FORM 257)

TYPING GUIDE SHEET

RATIONAL DECISIONMAKING IN TECHNOLOGY DEVELOPMENT

As you can discern from the title of my paper, today I would like to discuss our present methods for technological development in the environmental control field in the United States. You may also surmise from that title that I do not believe the present system represents a rational approach for the development and the implementation of technologies to resolve our environmental problems. Undoubtedly, our existing procedures often require us to utilize technologies which are either unproven or unjustified for environmental control programs.

One might question why such developmental work is critical to the environmental control field. Firstly, we must have rational decisionmaking in selecting technologies to achieve our environmental goals. All environmental controls represent a cost to society for the goods or services which each particular entity provides. If the cost to society of providing the environmental control technology greatly exceeds the benefits derived by the same society, then we are squandering our resources wantonly and without returning social benefits. One often hears the argument that we should continue to install environmental controls, even though the social benefits may not be identifiable, simply because environmental controls create jobs both in the construction and operation of such facilities. I believe this begs the question as to whether society can afford to squander resources on such technologies if they are not clearly beneficial to human health or the environment. Clearly, such resources could be invested in other job producing operations that will also benefit society.

Rational technological selections become particularly critical when you consider the circumstances in which the United States finds itself. For many years after World War II, the United States dominated the manufacturing capacity of the western world. However, in the 1960's our former enemies and allies began to make substantial inroads into the markets that were once exclusively those of the United States. Today we find ourselves in a very competitive world. We cannot simply ignore the external forces which affect our capability to continue spending huge quantities of precious capital for environmental facilities. John Dunne's pronouncement that "no man is an island", certainly applies in this case. While I make this point concerning environmental technology, the same is true of the other facets of international competition, including raw material costs, energy costs and the availability of productive labor at a competitive cost. The United States can no longer assume that we can continue to spend substantial quantities of capital and operating costs on environmental controls solely for the reason that they may create environmental jobs.

Before I get ahead of my subject, I believe it would be productive to examine the environmental technology selection process, as it now exists, and how it has developed over the years. For such an examination, we must go back to the legislation and regulations which are the driving forces behind technology and technology development in the environmental

EPA Form 2350-4 (4-80)
(PREVIOUSLY CIN. EPA FORM 287)

TYPING GUIDE SHEET

fields in the United States. Prior to 1970, we aimed most of our environmental regulatory efforts at eliminating visible sources of air and water pollution. There were numerous examples of visible sources to receive our attention. In the late 1960's and the early 70's during development of our environmental legislation on the national scene, we were bombarded with pictorial illustrations of scenes showing environmental pollution-smoking stacks, fish kills and discolorations of the water. The old enforcement conferences under the Federal Water Pollution Control Act of 1965 were mainly public relations hearings based upon visible evidence of pollution in our nation's waterways. Correspondingly, most of the efforts in the 60's and early 70's were directed at eliminating such visible sources. Then our nation went through the rapid development of extensive and complex environmental legislation-the Clean Air Act of 1970, the Federal Water Pollution Control Act of 1972 and the Resource Conservation and Recovery Act of 1976. The public's attention was clearly focused on these visible examples of gross pollution and the legislature responded with ample new legislation to deal with these issues.

The United States Congress is basically representative of the legal community. It is little wonder that any legislation to address a scientific problem such as pollution control would be dealt with in a legalistic approach. But the regulatory scientists of the time also joined in the framing of the environmental legislation, probably because of the frustration of trying to achieve the desired results from then existing legislation. The complexity of the resultant legislation became apparent as it took several years to implement the complex schemes developed by our lawmakers. The lawmakers, in turn, became frustrated because they could not see rapid change in our environmental circumstances and quickly moved to revamp these laws before they actually had a chance to be fully implemented. When a pendulum swings it does not stop in the center. Therefore, in midstream we had our legislators moving to establish a more complex system, as if the failure of complex legislation could be remedied by increasing the complexity. Congress therefore amended both the Clean Water Act and the Clean Air Act in 1977. They also added a footnote to the Resource Conservation and Recovery Act with the adoption of the Superfund legislation in 1980. This year RCRA again will be considered for amendment by the lame duck Congress.

Perhaps I am being too critical of our lawmakers in the development of these complex pieces of legislation since they did not accomplish it without help. Scientists in the regulatory field have done their share to make the regulatory process all the more complicated. It was not the legislators that came up with Reasonably Available Control Technology (RACT), New Source Performance Standards (NSPS), Best Available Control Technology (BACT), Lowest Achievable Emission Rate (LAER), Reasonable Available Control Measures (RACM), Prevention of Significant Air Deterioration (PSD), and Best Practical Control Technology (BPCT). We have even assaulted the King's English by asserting that the Best Available Control Technology is not better than the Lowest Achievable Emission Rate. While incorporated into the law, these acronyms and the technology selection processes they represent were derived by the regulatory community, made up of scientists presumably trained in

EPA Form 2250-4 (4-80)
(PREVIOUSLY KIN. EPA FORM 261)
TYPING GUIDE SHEET

the field. It becomes apparent when you view the provisions of our broad spectrum of environmental legislation, that the statutes are directed more at technologies than pollution control. The mechanisms are established by the laws that allow the regulatory agencies to select technologies for various reasons, none of which specifically addresses the idea of any environmental benefit to be derived from the technology. For example, the 1977 amendments to the Clean Air Act require the installation of Reasonably Available Control Technology (RACT) if a state cannot demonstrate achievement of the national ambient air standards by December, 1982. This provision has been used by the U.S. Environmental Protection Agency to establish essentially nationwide minimum technology for the steel industry. Since many of our urban areas will not achieve the ambient air standards, especially for particulate matter, the agency is applying such nationwide technology to almost the entire steel industry. We also have numerous examples of technology selection that are geared not to ambient effects but simply to the types of technologies available such as, BACT, LAER, BAT and PSES. The whole development of layer upon layer of technology defined requirements becomes suspect when they are apparently selected without any definition of benefits to society to be derived from the implementation of the technology. I recognize that the law is the law but one must then concede also that bad law is bad law, and bad regulations are bad regulations. I do not believe we can afford to continue our thrust towards the continued development of more costly technologies for pollution control without considering the benefits to be derived from such facilities. We must find a mechanism to more effectively select technology.

One major problem concerns new sources and the mythical ease with which technologies are installed for pollution control. In the beginning of the environmental movement, industry argued very strenuously that retrofitting pollution control facilities onto existing production units was more costly than installing the same controls on new sources. This is certainly true with respect to the capital costs of installing such controls. Operation and maintenance costs, however, may not be significantly reduced for new sources as compared to existing sources. This is particularly true if the new source requirements are substantially more stringent than those for existing sources. It appears that since the capital costs were less for a given control on new sources, the legislative and regulatory communities have decided that those funds should be dedicated to more stringent controls than those required for existing sources. This is all well and good as long as the environmental benefit for the incremental capital and O&M costs can be justified. However, if there is little environmental control benefit to be derived from the more stringent controls, we are essentially creating a disincentive to installing not only pollution control equipment but new sources themselves. I do not believe that this country can afford to install evermore stringent new source controls merely because the capital costs associated with new source controls are somewhat less than those for existing sources.

Beyond the philosophical and practical aspects of technology selection, we also must address the issue of requiring demonstrated and practical technologies for pollution control programs. In our haste to comply with stringent deadlines, regulators have been selecting technologies with less and less practical operating and maintenance experience before requiring the installation of such equipment on an industry-wide basis. There is no more startling example of forcing technology on an industry-wide basis than the scenario that the steel industry experienced with coke plant pushing emission controls. Here exists a classic example of an industry-wide technology forcing effort which literally resulted in the landscape being littered with unproven pushing emission control systems. I do not intend for both legal and practical reasons to enter into an extensive debate concerning this sad episode in our industry's environmental situation. Suffice it to say that the regulatory agencies were willing, based upon limited or non-existent data, to force a significant portion of the industry into installing unproven or poorly conceived technologies for controlling coke plant emissions.

A similar situation exists in the selection of technologies under the Clean Water Act where the agency has decided to utilize rather primitive pilot and bench scale experiments to formulate guidelines for the entire iron and steel industry. Industry does not move from such bench scale and pilot operations directly to full-scale production units for operating equipment nor do we expect that we should be forced to do so for environmental control purposes. In this respect, the United States should take a page out of the Japanese experience where technologies are slowly developed, escalated to full-scale units, proven viable and effective, and only then used on an industry-wide basis. American industry simply cannot dedicate capital resources for pollution control facilities which have not been proven effective for controlling environmental emissions.

I recognize that these issues are inherent in the legislative and administrative policies under which we presently find ourselves. But I do not believe that the present policies should remain sacrosanct considering the economic circumstances we now are experiencing. Our legislation and regulations were formulated under an assumption of economic activity that made such policies appear feasible. I must state emphatically that the American steel industry is not in a position to continue a business as usual posture in the environmental area.

The U.S. steel industry is presently at its worst level of operations since the depression years of the 1930's. Shipments in 1982 are projected at just over 60 million net tons, the lowest level since 1958. Capacity utilization is now running at a level below 40%, and for the year as a whole this figure is estimated to be below 50%, again the lowest level since the 1930's. This level of operations has had serious consequences for the industry's profitability and cash flow. Operating losses in steel continue at a staggering pace; almost $1 billion during the first half of 1982, and over $3 billion projected by Standard and Poor's for all of 1982.

I believe a timely reevaluation of our legislative and administrative policies is in order. The following issues should be included in such an evaluation:

(1) Technological requirements for existing sources should be based upon the environmental benefits to be achieved from their implementation and an examination of other cost-effective methods of achieving the equivalent environmental benefits.

(2) Technological requirements for new sources should not exceed those for existing sources unless it can be shown that controls for existing sources would represent a significant health risk.

(3) Technological requirements should not be implemented widely for specific sources until such technology has been demonstrated and proven in full-scale facilities over a reasonable time period. In this respect, anti-trust provisions regarding joint efforts for pollution control research and development should be eliminated.

(4) The driving force for much of our technological demands are the ambient standards that we seek to achieve. Such standards should be critically evaluated, and modified when the scientific data so indicates. The present National Ambient Air Standard for Total Suspended Particulate Matter (TSP) is an example which quickly comes to mind in this respect. This present standard has been discredited for many years, yet we are still imposing technological requirements on American industry in an attempt to achieve a discredited standard.

The people at this conference represent a considerable portion of those involved in the pollution control program in the domestic steel industry. Other industries have similar cadres of experts. I would encourage you to re-think our existing procedures and policies to improve our technological development and deployment. This plea is not a pernicious plot to undercut our basic environmental goals, but an appeal for a reconsideration and reevaluation of the technological merry-go-round on which we are inextricably caught.

EPA Form 2350-4 (4-80)
(PREVIOUSLY CIN. EPA FORM 287)
TYPING GUIDE SHEET

The work described in this paper was not funded by the U.S. Environmental Protection Agency. The contents do not necessarily reflect the views of the Agency and no official endorsement should be inferred.

ENVIRONMENTALISTS VS. THE STEEL PRODUCERS; ARE THERE ALTERNATIVES TO CONFRONTATION?

by: W. I. Goldburg
President, GASP, and
Professor, Department of Physics and Astronomy
University of Pittsburgh
Pittsburgh, PA 15260

ABSTRACT

Mutual distrust between environmentalists, steel company management and regulatory agencies may unnecessarily impede the solution to the nation's pollution problems. Experiences in Allegheny County provide the basis for some suggestions aimed at reducing this distrust.

I wish to express my appreciation to the organizers of this symposium, to the Environmental Protection Agency, and to AISI for inviting me to participate in this meeting.

I understand that this is not the first time you have invited a card-carrying environmentalist to speak at these symposia. The custom seems to be new enough, however, that some of the organizers are apparently still somewhat nervous about it. To those of you who share this apprehension, let me say that I don't blame you; I'm a bit on edge myself.

To dispel your concerns--or perhaps reinforce them--I offer a few words about myself and the environmental group with which I'm closely involved.

Like many of you I am a scientist, my discipline being physics. My own research has no direct application to pollution control. In fact, it has no direct application to anything. This is certainly one of the reasons that I have been active in such an applied activity as working for the improved quality of Pittsburgh air.

As to our organization, GASP was born thirteen years ago. You might say that we came in on a wave of revived public sensitivity to the fragility and interconnectedness of the environment. Perhaps we were the offspring of Rachael Carlson's landmark book, Silent Spring. Or maybe it was the photographs of the earth from the moon that gave us a send-off.

Of course, Pittsburgh's concern about air pollution long predates these two events. In fact, many would say that, as far as this city is concerned, the Clean Air Act of 1970 had the effect of fixing something that was no longer broke. That view would, I presume, find no supporters here.

For Pittsburgh there was something quite different about our environmental push of the 40's as compared to the nationwide revival of such concerns some fifteen years later. The stimulus for Pittsburgh's renaissance after WWII came from the business community, working hand in hand with community leaders and forward-looking politicians.

The impetus for Earth Day and the events which followed it, on the other hand, seems to have come from younger people and others, pressing on the system from the outside rather than the inside. At least that's my recollection of events. I also recall that the early 1970's was a time of popular distrust of those with economic and even political power. This distrust persists to the present, it seems, and detracts from the nation's ability to achieve solutions to our environmental problems. Still we are well-off compared, say, to Germany, where this type of distrust has evolved into open and dangerous political conflict.

Germany, with its Green movement may be at a political-environmental crossroad, and Professor Robert Reich of Harvard thinks that America is too. Referring to forewaves of regulatory reform that have swept the country in the last one hundred years, he concludes, that "Once each generation, American business has an opportunity to exert public leadership rather than defend itself against the public. It has that opportunity now." These waves of regulation, he says, were in each instance the result of corporate insensitivity to public needs, and were marked by "further extension of public control over business."

In this talk I want to reflect on whether the level of mutual distrust between environmentalists and the producers of steel can be reduced, or whether such distrust is intrinsic to our political-economic system. Stated in another way, are there alternatives to the adversary method of solving our environmental problems?

The engineers and scientists in this room, engaged as we are in problem solving, very likely do so in an atmosphere of cooperation, salted with the spirit of competition. Our problems are often so complex as to require combined attack by individuals of diverse training and skills--metallurgists, chemists, buyers, engineers of all types, a patent lawyer or two, and maybe even a physicist thrown in. The problem solvers are found by a common goal and a belief in the rightness of the overall enterprise.

How different it can be when environmentalists and industry representatives take a stand at a legislative hearing, or a lawyer's office, where a consent decree is being hammered out. Such adversary settings tend to extinguish all impulses for compromise. Further adding to the difficulties, the protagonists often regard themselves as spokesmen for their "cause"; who wants to risk being labeled as a traitor on return to one's own camp? Needless to say, these attitudes don't exactly grease the way to solving the pollution problem at hand.

I confess that when it comes to acting with religious zeal, we environmentalists are more to be censored than our sometimes opponents. Nevertheless, one sees matters of "principle" often influencing the stance taken by those from industry. One such unspoken principle is "government involvement leads to government intrusion." A logically indefensible principle we both seem to cherish is "don't set a precedent if you can help it."

Let's put causes aside and consider whether there are untried instruments or modi operandi that environmentalists and corporate decision makers can create that will enhance our success rate in solving problems that the care of our environment imposes upon us. Perhaps I should use the words "solve at acceptable cost," but I rather thank that the finding of an acceptable cost is part of the solution we seek.

In some sense, the problem, as I have phrased it, is improperly posed, for it contains the implicit assumption that corporate executives and environmentalists are mutually exclusive groups. While this is certainly not so, we must acknowledge that our axes of central concern are displaced from each other.

Some of you may perceive the conflict as arising between responsible and irresponsible environmentalists. However one may see it, honesty requires that we acknowledge the existence of a barrier of distrust if not of values between us. It is this barrier that we might consider lowering, while recognizing that its removal is probably neither possible nor desirable.

One might classify the problems we face into three types--technical, regulatory, and philosophical (the philosophical aspect may be thought of as political or even religious). Running through all three categories is the problem of costs and how to apportion them. I will remark on only the first two of these, generalizing from GASP's experience in Allegheny County. Probably some of my generalizations are false in which case I hope you will tell me personally or in the discussions to follow.

Over a decade ago I visited an executive at United States Steel Corporation, to suggest that, as an academic and an environmentalist, I might be able to help in the solution of one or more of the company's pollution problems. As a result of prior discussions with others, I concluded that there were some engineering faculty members who would be willing to devote a portion of their time to this task.

It was admittedly a naive suggestion on my part, but probably not deserving the poor reception it got. In a manner befitting a parent gently admonishing a child, I was told that United States Steel already had all the technical know-how it needed; the only missing element was money. The interview hardly took more time than my trip upstairs on the elevator.

The incident would not deserve mention, did I not sense that a remnant of that machismo attitude persists to the present. Of course, no one can stand a blow below the belt, so even the steel industry seeks governmental protection from unfair external competition.

Even if the steel companies are right in wanting to go it alone, they get more sympathy and cooperation from environmentalists when we're rung in on the problems you are facing. Without such evidence to the contrary, we--and the public at large--conclude that the steel industry is engaging in a continuous struggle to delay meeting legal and ethical obligations to protect the quality of our environment.

A more open approach has been tried in Pittsburgh. Though company officials have denied environmentalists permission to accompany regulatory people on plant inspection tours, we have been invited to visit a major steel industry research laboratory to see for ourselves what the company was doing to solve its coke oven door emission problems. I suggest such experiments as this be tried more often.

To be fair about it, it should be said that disdain and distrust of environmentalists is sometimes found in regulatory agencies. To illustrate, when GASP sought to carry out some high-volume sampling measurements ourselves, we were forbidden from borrowing an instrument for the purpose. When we were subsequently offered such an instrument by another agency, we were forbidden from locating it next to the first agency's sampler, for calibration purposes. The unspoken reason, of course, was distrust. And why was GASP entering the monitoring business? Again, distrust, though we might prefer to call it vigilance.

This episode is recalled not to assign blame but to suggest that distrust is best minimized by environmentalists, regulators, and industry exposing each other to continuous scrutiny.

On our local scene the above incident is an exception and not the rule. Distrust is minimized by the frequent contact many of us enjoy at meetings of the County's Air Pollution Advisory Committee. Its members are appointed by the County Commissioners. Under guidance of the County's Air Pollution Bureau, the Advisory Committee deals with issues both large and small. For example, the Committee has the responsibility for creating the County's SIPs, though final approval comes from elected officials. The Committee reviews Bubble proposals and also deals with issues put before it by citizens and representatives of various groups, including the United Steel Workers at GASP.

The mutual respect and friendship engendered by our contacts at Advisory Committee meetings broadly influences how pollution control decisions are made here. Sometimes issues and incidents arise that temporarily destroy this mutual trust, and both the public and local industry suffer a loss when this happens.

One sure way to generate suspicion and distrust is for any party to withhold data which form the basis for conclusions or calculations. Environmental groups and regulatory agencies are sometimes asked to accept results that they have no way of verifying. When this happens, it is hard to find comfort in claims of corporate confidentiality. Here in Pittsburgh a steel worker's local had to go to court in order to find out how their own jobs might be affected by a stretch-out plan. Again, the information was withheld by the company on the basis of a confidentiality claim.

I do not think that professed corporate concern about the competition is generally insincere or without foundation. But I do feel that appeals to confidentiality can adversely intrude into environmental issues. Since pollution control is of direct value to the public, might it be worth considering the creation of new political and financial mechanisms for dealing with the costs? It seems to me that as long as pollution control technology is strictly handled as a salable commodity, its flow will be restricted--to the public detriment. I can see why companies would want to break their necks to make a better product, but I can't see a similar incentive for making coke in a cleaner way.

Next, I turn to the problems produced by distrust on the regulatory side. In the steel industry, major regulatory problems are usually settled by compromise. The compromises usually take the form of consent agreements. These agreements are generally the result of a company's failure to live up to requirements imposed by national or state laws.

Often the company responsible for the violations comes back into court, seeking a revision of the agreement on the grounds that it cannot meet the conditions initially agreed to (rarely, if ever, does the initiative for revising an agreement come from the regulatory agency, with the assertion that the conditions of the original agreement have proved to be inadequate from the public's point of view).

Often--though not always--environmental groups oppose these contract-breaking revisions, sensitive as they are, to the compromises that initially went into their making. Companies, like individuals, lose their believability when they fail to keep their word. The resulting disillusionment is further magnified when informed citizen's groups are barred from participation in discussions of the revision.

We are kept out, I conjecture, because of corporate distrust. It is presumed, I suppose, that we have no understanding of economic realities and therefore are likely to exhibit irrational inflexibility.

Let me cite a particular example that was both heartening and discouraging at the same time. When GASP asked a highly placed steel company official if we could be party to discussions of a very important consent agreement, his reaction was, "Sure." From his point of view, the company had nothing to hide and nothing to be ashamed of. He presumably believed that his firm's best interests would be served if the revision discussions were as open as possible. The official did say, however, that we must check with the law firm which represented them. The lawyers presumably concluded that we were not to be trusted, for they strove diligently to keep us out.

Pollution control agreements with steel companies often don't stick because the industry finds it impossibly difficult to make long-range plans. Does the cyclic nature of the enterprise require that solutions to its pollution problems have an erratic component? If so, corporate distrust on the part of environmentalists and the public will surely remain difficult to surmount.

Might we, on the other hand, jointly enter into a search for new financing schemes aimed at increasing the likelihood that environmental commitments will be met?

In summary, there is probably no way of completely escaping the adversarial element, as we seek to solve environmental problems in general and the problems of the steel industry in particular. At the same time we should strive to decrease the distrust that often seems to inferfere with the achieving of our common goal--that of enhancing the quality of our air and water at a socially acceptable cost. To accomplish this, we may want to consider new schemes that will increase the steel industry's ability to effectuate its long-range environmental protection plans.

We may also want to consider new nonadversarial ways of increasing the exchange of ideas and points of view between corporate decision makers and environmentalists. Experience informs us that such exchanges reduce distrust, increase respect, and ease the way to compromise.

This paper has been reviewed in accordance with the U.S. Environmental Protection Agency's peer and administrative review policies and approved for presentation and publication.

THE GEOGRAPHIC APPROACH TO INTEGRATED ENVIRONMENTAL MANAGEMENT

by: Michael R. Alford, Chief
Geographic Unit
Integrated Environmental Management Program
U.S. Environmental Protection Agency
Washington, DC 20460

ABSTRACT

EPA and its counterparts at the state and local levels have historically attacked pollution problems by establishing separate programs for each of the three environmental media--air, water, and solid waste--and have required polluters to reduce their impacts through specified control technologies. This approach has resulted in substantial progress toward national environmental quality goals. It now appears appropriate, however, to supplement this traditional focus with other integrative mechanisms, in order to move toward the solution of the remaining problems. The fact that our control strategies do not simultaneously address all media has led to control efforts that may be less effective and more costly than they might have been.

The Integrated Environmental Management Program (IEMP) in EPA's Office of Policy Analysis is developing methods to help solve emerging environmental problems in a more cost-effective manner. IEMP is now working on methodologies for integrating controls on an industry basis, by examining environmental problems and controls as they relate to specific industrial sectors. The other mechanism under study in IEMP, the geographic approach to program integration, is the subject of this paper.

THE REASONS FOR GEOGRAPHIC INTEGRATION

The uniform, nationally applicable pollution abatment standards which EPA writes do not bring about uniform levels of environmental quality. No matter how carefully EPA writes such regulations, there will always be geographic areas where populations and sources of pollution are so concentrated that total environmental risk may remain unreasonably high even after the application of standard controls. These areas are likely to have persistent problems in attaining national ambient standards for conventional pollutants, and experience has shown that they are also likely to have problems involving toxic substances.

In a review of national data bases, IEMP found that a relatively small number of areas accounts for a significant share of the nation's industyial activity and pollutant loadings. IEMP has identified 100 counties which account for 38% of the nation's population, 35% of total hydrocarbon emissions to air, 39% of the nation's hazardous waste facilities, and 25% of national chemical production. Yet these counties account for only 3% of the country's land area. Such figures suggest that these few areas could benefit from especially close attention.

Because each of these areas has unique industrial and environmental characteristics, the most effective strategy is likely to be to treat them on a case-by-case basis. Such case-by-case analysis is expensive and difficult, but appears to be justified in certain areas with large populations, high concentrations of industry, and potentially serious environmental risks.

Because of the complexity and difficulty of the environmental problems in these areas, that case-by-case treatment should involve the development of control strategies that are tailored to local conditions, rather than relying exclusively on further national regulation oriented heavily toward prescriptive engineering. A case-by-case approach should examine the whole chain of pollutant sources and environmental pathways to get a comprehensive picture of the area's environmental problems, and should base control strategies on environmental exposure and risk.

PAYOFFS OF THE GEOGRAPHIC APPROACH

Taking an unusually close look at a relatively small number of geographic areas should result in payoffs not achievable under traditional regulatory mechanisms. It allows EPA, in conjunction with state and local governments, to look at all environmental media at once and to focus resources on the most pressing problems. It also allows for the design of control strategies which are tailor-made to local conditions.

Perhaps most important, the approach allows for explicit consideration of a great deal of relevant information which, under traditional regulatory procedures, is not conveniently available or systematically presented. Toxic substances released to the environment are often transferred from one environmental medium to another. Changes in regulatory controls result in inter-media pollution transfer and changes in risk to subpopulations. The integrated methodology enables policy-makers to consider these facts in making decisions on

EPA Form 2360-4 (4-80)
(PREVIOUSLY CIR. EPA FORM 257)
TYPING GUIDE SHEET

how to invest their own resources and those of industry.

The application of these new approaches does not imply that previous efforts have been unsuccessful, nor that EPA plans to abdicate its traditional responsibilities in addressing environmental problems in more typical geographic areas. Rather, the work of the Integrated Environmental Management Program is designed to supplement past and current activities in order to focus resources on the most serious remaining problems, and to address those problems in the most sensible manner. EPA hopes that the methodologies the geographic approach is developing will prove useful to state and local governments in addressing the environmental problems of the eighties.

The next two sections of this paper discuss the scientific and economic methodologies IEMP proposes to use in studying densely populated, heavily industrialized areas in order to devise better strategies for pollution control, and the institutional methodologies IEMP plans to use to implement those strategies. The paper then describes a pilot study now in progress in greater Philadelphia to test those methodologies and to increase their applicability to other areas. It concludes with a short discussion of IEMP's preparations for the years ahead.

THE TECHNICAL METHODOLOGY OF THE GEOGRAPHIC APPROACH

The basic model proposed by the Integrated Environmental Management Program for the technical analysis of densely populated and heavily industrialized areas is shown in Figure 1. Its unifying method is to compare problems on the basis of environmental exposure and risk. Its goal is to relate information on emissions of pollutants and the environmental pathways through which the pollutants travel, to the ultimate human exposure levels and resultant levels of environmental risk. It also provides for the relation of information on environmental risk levels to actual health effects found in epidemiological studies.

Risk levels can also be related to economic data and information on pollution control costs to determine more efficient ways for governments at any level to improve the protection of public health, and to identify places where the existing regulatory structure can be made more effective. IEMP thus proposes to examine the economic and environmental impacts of the control options available at all levels of government within a framework of cost-effectiveness analysis, and to provide recommendations to Federal, state, and local policy-makers.

BEGIN FIRST LINE OF TEXT HERE
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD, BEGIN SECTIONS HERE
BEGIN LAST LINE OF TEXT
3/8"
BOTTOM OF IMAGE AREA, OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
EPA Form 2350-4 (4-80)
(PREVIOUSLY CIN: EPA FORM 237)
TYPING GUIDE SHEET

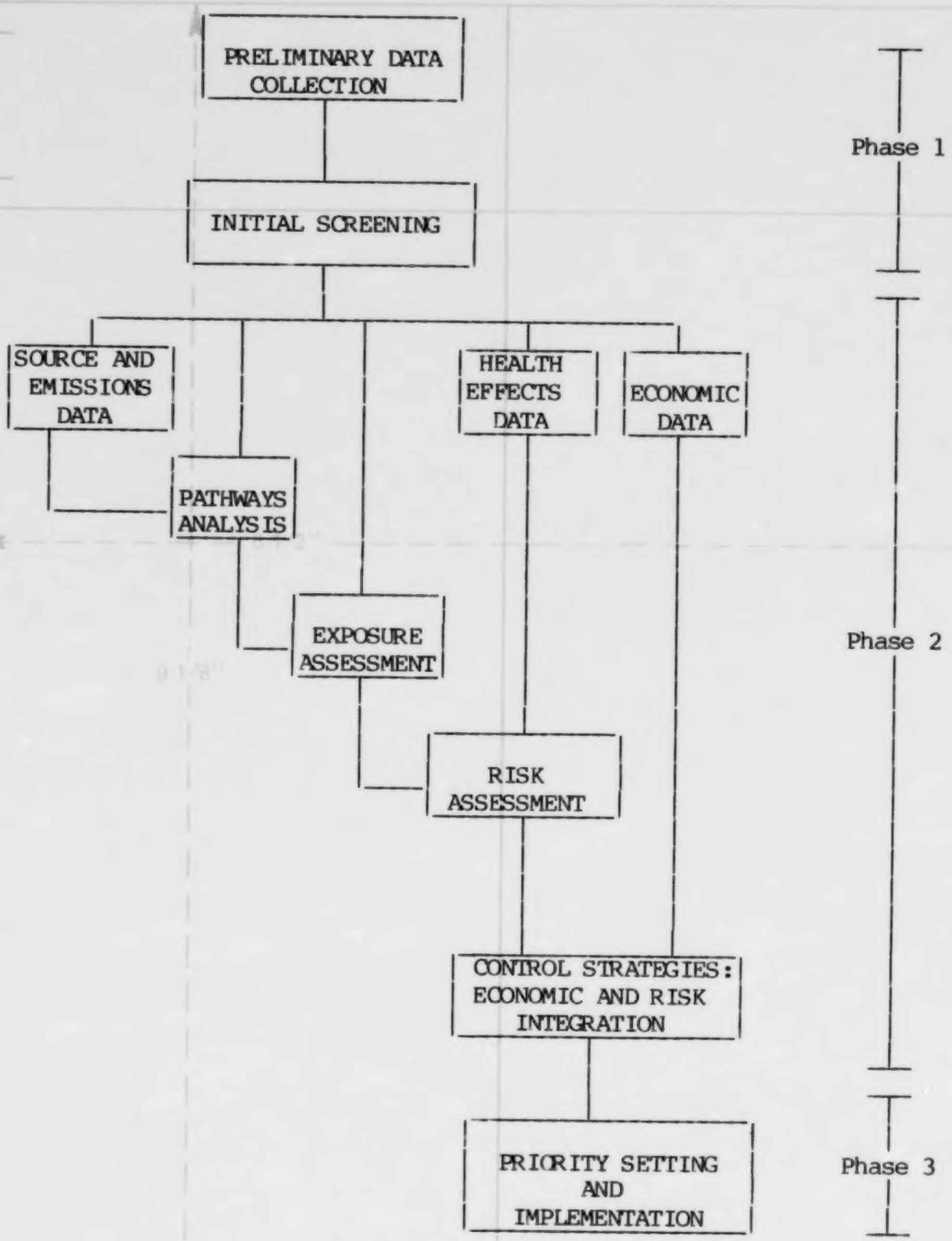

PRELIMINARY DATA COLLECTION
INITIAL SCREENING
SOURCE AND EMISSIONS DATA
HEALTH EFFECTS DATA
ECONOMIC DATA
PATHWAYS ANALYSIS
EXPOSURE ASSESSMENT
RISK ASSESSMENT
CONTROL STRATEGIES: ECONOMIC AND RISK INTEGRATION
PRIORITY SETTING AND IMPLEMENTATION
Phase 1
Phase 2
Phase 3

Figure 1. Chronological Flowchart of the Geographic Approach's Analytic Methodology.

Applying the Best Available Science to Integrated Geographic Studies

New scientific and economic procedures, developed by EPA and other governmental bodies, and by groups in the private sector, can increase our understanding in each of these methodological areas--from estimating emissions to assessing the economic impacts of different regulatory strategies. They can also help managers at all levels of government cope with the pervasive problems of uncertainty and incomplete information. IEMP plans to bring the best scientific analysis to bear on environmental problems.

To assist in the analysis of pollutant sources, IEMP is preparing a handbook that covers methods for characterizing and quantifying pollutant loadings from different sources in the absence of complete information. The handbook will describe the uses and limitations of each within the context of the geographic project's methodology, and will include a catalog of emission factors which are specific to particular industrial and other sources. It will be useful in filling gaps in source and emissions data and in augmenting the usefulness of emissions monitoring programs.

For the analysis of the pathways traced by pollutants after they enter the ambient environment, IEMP is compiling a catalog of models of environmental pathways in all environmental media. The catalog is designed to assist scientists in selecting the best model for a particular kind of analyis, and will include notes on the uses and limitations of different models. It will pay particular attention to models which can be used in analyzing transfers of pollutants from one environmental medium to another, since these inter-media transfers are likely to be particularly important in analyzing toxics problems. The models can be verified by selective ambient monitoring in the field.

IEMP is also preparing a handbook on the assessment of exposure and risk. It will describe methodologies for evaluating human and ecosystem exposure using information on sources, pathways, and ambient conditions. It also will discuss methodologies for relating exposure estimates to information on health effects to estimate and extrapolate environmental risk.

Finally, IEMP is working on the development of methodologies for assessing the economic impacts of present pollution control requirements as they relate to their environmental effects, and for analyzing the existing structure of environmental regulation in order to assess the legal and institutional feasibility of implementing further, more cost-effective controls. The analysis of existing regulatory structures will take into account statutes, regulations, and administrative procedures at the Federal, state, and local levels. Control options which are legally and institutionally feasible can then be analyzed in terms of environmental and economic effects.

Perhaps the single greatest advantage of this comprehensive, multi-media methodology is that it provides decision-makers with a great deal of relevant information which, under traditional regulatory procedures, is not readily available or systematically analyzed. For example, it allows for explicit consideration of the inter-media transfers of pollutants that occur as a result of regulatory requirements, and of the changes in risks to subpopulations that occur when environmental controls are changed. It thus provides a powerful new tool to environmental officials at all levels of government. Although the tool may not be appropriate for dealing with traditional problems involving conventional pollutants, it can potentially make a significant contribution in moving toward the solution of cross-media toxics problems.

The documents which IEMP is preparing will be submitted for peer and administrative review within the Agency. In addition, IEMP will submite them to the EPA Regional Offices and to state and local environmental agencies for review. This review process will ensure the validity of the methodologies and will increase the usefulness of the documents to EPA Regional, state, and local staffs.

The Institutional Methodology of the Geographic Approach

The technical methodology described above must be thoughtfully implemented in order to have a real effect on environmental problems. Translating technical analyses of problems into implementable program decisions requires coordination in two dimensions: the scientific and economic pieces of the technical methodology must be integrated over time, and the roles of all actors within and outside the government must also be integrated in a practical way.

To coordinate the analytic pieces of the methodology in such a way as to maximize the efficiency of resource use, IEMP plans to use a phased approach. It will not ordinarily be feasible to conduct exhaustive analyses of every potential environmental problem in a large, diversified urban area. The first phase of a study thus involves screening environmental problems on the basis of readily available information, with priority problems analyzed more thoroughly in the second phase.

The first phase entails gathering existing data on pollutant sources, emissions, and pathways, on resultant exposure and risk, and on the industrial economics of the area. On the basis of these existing data, study participants (including EPA and state and local officials) can formulate a list of environmental problems, ranked in order of severity, which appear to be the most pressing and thus the best candidates for further study.

In the second phase of the study, the priority problems will be analyzed according to the same methodology but in considerably more detail. Study participants will characterize emissions and model environmental pathways and exposures; this analytic work will be supplemented, where necessary, by monitoring of emissions, effluents, and ambient conditions, and possibly by direct monitoring of body burden uptake as well. During this second phase of the analysis, which is expected to take up to a year, the participants will also undertake analyses of the costs imposed on firms by various legally and institutionally feasible strategies for addressing these problems.

Policy-makers at all levels of government will have to be actively involved from the outset, and will have to reach conclusions on appropriate government actions in consultation rather than unilaterally, if positive change is to occur as a result of an integrated geographic study. One way to ensure that this happens is to convene two committees upon initiation of a study, with representatives from EPA and from state and local environmental agencies.

The first will be a steering committee composed of policy-level officials from EPA and from the state and local governments in the study area. This committee will direct the study and make final decisions about which problems should be analyzed, what methodologies should be used, and what controls implemented. The final policy judgments will be up to this committee, although it will rely heavily, in its decisions, on the technical work conducted in the study.

The second will be a technical committee composed of staffs from EPA, from all state and local governments affected by the study, and, where appropriate, from other governmental bodies (e.g., councils of governments and regional commissions) as well. This committee will review the study area boundaries, problem selection, technical analysis, and control opportunities, and pass on its recommendations to the steering committee. Its work will ensure the comprehensiveness and scientific rigor of the

EPA Form 2350-4 (4-80)
(PREVIOUSLY CIN EPA FORM 287)
TYPING GUIDE SHEET

study, and allow an equal voice for each affected government. To be successful, an integrated geographic study needs to gain the support not only of the state and local governments but also of industry and public interest groups in the area. While it does not appear appropriate for private sector organizations to be represented in the technical and steering committees, it is clear that they should be encouraged to participate in the project and review the work. A number of mechanisms could be used for this purpose, among them the establishment of a citizens' advisory committee. Because the relations of state and local governments with industry and public interest groups vary dramatically from area to area, the nature and extent of public participation should probably be decided by the steering committee of each individual study.

The Philadelphia Project

In the summer of 1982, IEMP began discussions with the City of Philadelphia and the States of Pennsylvania and New Jersey with the intent of conducting a pilot geographic study in the greater Philadelphia area. All three of these governments have agreed to participate actively in the study, sending representatives to the technical and steering committees and assisting EPA in its scientific and economic analyses.

In this study, IEMP plans to demonstrate that its analytic methodology for conducting an integrated geographic study works, and that, by conducting the sort of analysis discussed above, it is possible to discover ways to better allocate governmental and industrial resources in order to increase the payoff in environmental quality. Second, IEMP wants to show that the institutional methodology can work as well: that EPA can improve the way it does business with state and local governments, and that officials from all three levels of government can work together to implement better policy. The payoff for the state and local governments, assuming that the study is a success, should be improvements in environmental quality for less cost. IEMP will also benefit from the opportunity to refine its methodology, where necessary, in the light of the Philadelphia experience.

Philadelphia was chosen for several reasons. It has already been extensively studied, and data on environmental conditions in the area already exist in considerable quantity and quantity. The environmental staffs of both states and the city are experienced and expert. Philadelphia also has a diversified industrial base and a wide variety of pollutants and sources, and it is drained by both tidal and non-tidal rivers: it is thus an intrinsically interesting site from an environmental point of view.

The study area consists of all of Philadelphia County, whose boundaries are coterminous with those of the city, and parts of seven other counties as well: Bucks, Chester, Delaware, and Montgomery in Pennsylvania, and Burlington, Camden, and Gloucester in New Jersey. The eight counties in the study area had a 1980 population of 4,716,818, making the Philadelphia metropolitan area the fourth largest in the country.

The list of organizations involved in the study includes such regional organizations as the Delaware River Basin Commission in addition to two EPA Regional offices, two states, and the City itself. All of these organizations are represented on the technical committee; the steering committee consists of the Director of EPA's Office of Policy Analysis, EPA's Regional Administrator for Region III, and high-level representatives from the City of Philadelphia and from the States of New Jersey and Pennsylvania. Phase one of the study is now nearing completion.

IEMP plans to screen problems in the area on the basis of risk during November and December. The technical and steering committees will meet to consider these recommendations in January and February, 1983. Over the ensuing ten months, staffs from EPA, the City, and the two states will conduct detailed analyses of the priority problems, with ongoing direction from the project steering committee. Recommendations on controls which should be implemented will be presented to the steering committee in October or November, 1983.

IEMP hopes that most of the recommended controls will be implementable at the state or local, rather than the Federal, level. Federal regulation to address local toxics problems, while always an available option, is unlikely to be the most cost-effective strategy. State and local governments have more flexibility as well as a stronger incentive to balance the costs and benefits of environmental controls.

For these same reasons, IEMP anticipates that the recommended controls may include a number of innovative strategies which have not been implemented at the Federal level. Federal environmental regulations, in the interests of equity and

EPA Form 2350-4 (4-80)
(PREVIOUSLY CIN. EPA FORM 257)
TYPING GUIDE SHEET

ease of enforcement, have relied heavily on design or engineering standards. The optimal strategies for toxics control at the state or local level, however, may include substantial use of alternative control strategies such as controlled trading and cost sharing. Again, the advantages of the geographic methodology are that it allows solutions to be tailored to local problems, and that it allows for explicit consideration of the impacts of any control strategy, including its economic effects, its effects on pollution into all environmental media, and its impacts on the risk of subpopulations.

The Future of the Geographic Approach

The work this year in Philadelphia should result in improvements in environmental management in that area, and in improvements in the analytic methodology based on the experiences of the demonstration study. That study, however, is only part of an overall strategy aimed at addressing environmental problems in other geographic areas across the country. IEMP is taking other steps to improve the methodology further and to work toward future studies in other areas.

IEMP is actively soliciting the opinions of EPA Regional Offices and state and local environmental officials on the merits of the methodology to increase its usefulness to state and local governments. EPA Regional, state, and local officials know what approaches are likely to work in their areas, and will be able to tell IEMP whether strategies that worked in Philadelphia will work in other possible sites for geographic studies, and what other approaches not tried in Philadelphia are likely to be applicable in other areas. Since the methodology must ultimately be tailored to local concerns, it is important for IEMP to improve its understanding of what those concerns are likely to be.

The other purpose of opening a dialogue with state and local officials is to develop a body of information on appropriate sites for future geographic studies. Looking at nationwide data bases gives a rough sense of where integrated studies may be appropriate, but many other factors, both technical and institutional, must be considered as well. IEMP's discussions with Regional Offices and with state and local staffs will expand its knowledge of those areas and allow work to begin at other sites in late 1983 or 1984.

EPA Form 2350-4 (4-80)
(PREVIOUSLY CIN. EPA FORM 287)
TYPING GUIDE SHEET

* * *

The geographic approach to integrated environmental management is not expected to solve all the nation's environmental problems. EPA believes, however, that it is an important step in the right direction. It will bring EPA and state and local governments together in a new forum for real cooperation. It will allow them to set priorities across media rather than looking at the environment as discrete boxes labeled air, water, and solid waste; they can, therefore, act with the assurance that they are investing the resources of government and industry in addressing the most pressing problems first. And it will allow them to use the best regulatory tools for the job, to tailor controls to the unique environmental, economic, and social conditions in an area, and to bring about improved environmental protection in a more sensible way.

PANEL: ENVIRONMENTAL TRADE-OFFS

Chairman: Michael R. Alford
Chief, Geographic Unit of the
Program Integration Project
U.S. Environmental Protection Agency
401 M Street, S. W. (PM-219)
Washington, DC 20460

Panel Members: Stanley L. Laskowski
U.S. Environmental Protection Agency
6th and Walnut Streets
Philadelphia, PA 19106

William L. West
Republic Steel Corporation
P. O. Box 6778, Room 520-R
Cleveland, OH 44101

Walter I. Goldburg
Group Against Smog and Pollution
1237 Murdoch Road
Pittsburgh, PA 15217

The panel discussion was not recorded.

SESSION 1: MULTIMEDIA POLLUTION ABATEMENT

Chairmen: Michael R. Alford
Geographic Unit of the Program
Integration Project
U.S. Environmental Protection Agency
Washington, DC

Joseph G. Crist
Environmental Evaluation
U.S. Steel Corporation
Monroeville, PA

EPA Form 2350-4 (4-80)
(PREVIOUSLY CIN. EPA FORM 227)
TYPING GUIDE SHEET

Although the research described in this paper has been funded wholly or in part by the U.S. Environmental Protection Agency, it has not been subjected to Agency review and therefore does not necessarily reflect the views of the Agency and no official endorsement should be inferred.

MISSION AND RESEARCH PROGRAMS OF THE INDUSTRIAL WASTE ELIMINATION RESEARCH CENTER

by: James W. Patterson, Ph.D.
Professor and Chairman
Pritzker Department of Environmental Engineering
Director, Industrial Waste Elimination Research Center
Illinois Institute of Technology
Chicago, IL 60616

ABSTRACT

The Industrial Waste Elimination Research Center (IWERC) was established in 1980 at Illinois Institute of Technology, under the sponsorship of the USEPA Centers of Excellence program. The Center, operated by IIT in consortium with the University of Notre Dame, is concerned with fundamental research directed toward the avoidance, abatement, or elimination of the generation of air, water and solid pollutants. The Center, now in its second full year of operation, is supporting five major research projects. This paper discusses the mission and objectives of the Center, and presents research objectives and results.

INTRODUCTION

Management of industrial wastes has become a major international problem and target of public concern, as a result of increased recognition of the immediate and long-term hazards to human health and the environment from the wastes generated by industry. IWERC, a consortium of Illinois Institute of Technology (IIT) and The University of Notre Dame (UND), is dedicated to research on fundamental aspects of industrial wastes management, associated with in-plant recovery and containment, avoidance, or reduction of pollutant discharges. This consortium of the two midwestern universities, Illinois Institute of Technology and the University of Notre Dame, represents a strong commonality of background, substantial staff expertise in environmental and chemical engineering, chemistry, and related disciplines, and dedication to exploratory research related to the mission of the Industrial Waste Elimination Research Center. The center research focus is multi-media, and primarily concerned with reduction and elimination of industrial pollutant discharges through innovations in industrial processes and development of recycle/recovery

EPA Form 2350-4 (4-80)
(PREVIOUSLY CIN. EPA FORM 287)
TYPING GUIDE SHEET

strategies.

Historically, the attention of both environmental engineers and regulatory authorities has been almost wholly focused upon end-of-pipe treatment, usually of composited, self-diluting waste streams gathered from across a whole industrial facility. It is likely that this "end-of-pipe" technological and regulatory mentality has discouraged efforts directed toward many fruitful opportunities for innovation, particularly within the manufacturing facility itself, at the very point of pollutant generation and where it is in its most concentrated and consistent form, and isolated circumstance. If we blend one isolated process stream with others of dissimilar nature for end-of-pipe treatment, the opportunity for innovative control is lost, and replaced by the necessity for brute non-selective control procedures.

It is within the manufacturing plant that manufacturing process modifications, such as raw feed stock prepurification, or changes in reactor conditions can take place. It is within the plant that innovative clean manufacturing processes can be introduced, to reduce or eliminate the occurrence of unwanted side reactants or loss of valuable raw materials or product. And it is within the manufacturing plant, at the point of waste generation that the opportunity for pollutant capture is greatest and where we must initiate our programs in recovery, recycle and reuse. I do not exclude the opportunities for innovation in end-of-pipe technology, but I do believe that opportunities for in-plant innovation for industrial pollution abatement at least match, and perhaps exceed, those associated with end-of-pipe treatment.

IWERC is one of eight national Centers of Excellence established by the EPA in response to Congressional concerns that the agency was not adequately supporting long-term, fundamental environmental research. It is one of three technology-oriented centers in the program, with its charter being to concentrate exclusively on in-plant aspects of pollution control. The other technology centers are the Advanced Environmental Control Technology Research Center (University of Illinois) and the Hazardous Waste Research Center (Louisiana State University). The other two technology centers concentrate their effort on end-of-pipe treatment and hazardous waste problems, respectively. All three technology centers have in common the assignment to carry out research at a fundamental level, oriented toward generic problems.

IWERC is a problem-oriented exploratory research center utilizing the tools of basic science and engineering to perform research directed at industrial waste elimination. The principal areas of focus of IWERC research are:

Metals Speciation and Separation
Sorption/Desorption Phenomena
Particle Size and Shape Conditioning
Anaerobic Management of Industrial Pollutants
Membrane Processes and Applications
Process Catalysis and Control

Through its coordinated research program on fundamental aspects of industrial waste elimination, IWERC is contributing to a better understanding of the opportunities and technologies appropriate to eliminate, reduce or contain industrial pollutant discharges, and thereby avoid or reduce the need for and/or costs of end-of-pipe control.

CENTER ORGANIZATION

The Center is headquartered on the IIT campus, in Chicago. Dr. James W. Patterson is the Center Director. Institutional Program Managers represent each of the two member institutions of the Consortium. The Program Managers provide local administrative support and intra-campus coordination for campus-specific Center sponsored programs and, with the Center Director, serve as the senior administrative staff of the Center.

The Center's programs are overseen by a Policy Board consisting of senior EPA officials, the Directors of the other two technology-oriented research centers, and the Director of IWERC. In addition, two advisory councils have been set up to provide input from a cross-section of science and industry on the direction of research pursued by the Center.

The Policy Board establishes broad guidelines for IWERC research and operations, determining the overall goals of the Center. It is the responsibility of the IWERC Director and the science and industry advisory committees to determine specific research projects which fit within the overall goals as established by this Board. The Scientific Advisory Committee (SAC), consisting of research-oriented representatives from industry, other universities, and federal research facilities, assesses the quality of each proposal submitted to the Center and follows up with an evaluation of the ongoing and completed research. The Industry Advisory Council (IAC), made up of senior environmental managers who represent most major industry categories, provides the IWERC researchers with practical perspectives on industrial problems and helps to establish mechanisms for the ultimate review and transfer of IWERC research results to private industrial settings. The Center has actively sought the cooperation of industry, both for the insight working engineers can give on the problems under study and for the later recruitment of industrial plants for field testing.

Annual program review meetings are held during June of each year. These meetings offer the opportunity for mid-project year review of the Center projects. The program review meetings are attended by the Policy Board, SAC and IAC, plus other selected engineers and scientists within and external to the Center. During Year 01, two research projects and five research planning projects were approved by the IWERC Policy Board, and authorized for funding by the Center Director. All projects were of one-year duration. These projects are listed (Projects 8001-8007) in Table 1.

The general publication policy of IWERC is to publish research planning project reports as internal documents of the Center, and to publish the results of research studies in peer-reviewed scientific and technical journals. One exception to this policy is that three of the Year 01 planning project reports will be commercially published as the three-volume series Industrial Waste Management, by Ann Arbor Science Publishers, Inc., Ann Arbor, Michigan. Publication of this series through a commercial publisher will provide for greater availability of these IWERC reports than would be possible with the limited financial resources of the Center.

The Center is involved in a number of ancillary activities compatible with the mission and objectives of IWERC. These include a Visiting Scholars Program; presentations at conferences and briefings by Center researchers to industrial associations and corporate environmental staff; and a cooperative research program with the Italian National Research Council, under a U.S. - Italy Cooperative Research Agreement. The Visiting Scholars Program is designed to bring industry and other researchers with research interests compatible with or complementary to the research interests of IWERC to the consortium campuses to exchange and review research findings and explore future research directions.

CURRENT CENTER ACTIVITIES

Five research projects are currently being coordinated and funded under IWERC sponsorship during Year 02 (see Table 1, Projects 8201-8205). These projects focus on metals recovery, sorption/desorption recovery for organics, liquid-liquid membrane extraction techniques for organics and metals, and catalysis.

Nine research proposals were submitted to IWERC for Year 03 funding. These proposals have been reviewed by the SAC, and several proposals are in the process of revision to reflect SAC review comments and recommendations. The revised proposals will be returned to the SAC for final review,

TABLE 1. SUMMARY OF YEAR 01 AND 02 PROJECTS INDUSTRIAL WASTE ELIMINATION RESEARCH CENTER

Project Number	Principal Investigator(s)	Project Title
8001	Theis, Jennings, Selman	Identification of Research and Planning Needs for Industrial Waste Management
8002	Noll	Planning Project; Recycle, Recovery and Reuse of By-Product Pollutants
8003	Tavlarides	Process Modifications Toward Minimization of Environmental Pollutants in the Chemical Processing Industry
8004	Ivory	New and Innovative Industrial Pollutants by Anaerobic Processes
8005	Obayashi, Ketchum	Management of Industrial Pollutants by Anaerobic Processes
8006	Wolf	Infrared Studies of Surface Dynamics During Heterogeneous Catalytic Reactions
8007	Patterson, Theis	Speciation and Separation of Transition Metals in Multi-Phase Environments
8201	Noll	Evaluation of the Dynamics of Multicomponent Sorption/Desorption Processes with Differential Reactor Columns
8202	Haas	Metals Speciation and Separation
8203	Theis	The Effect of Speciation on the Sorptive Behavior of Metal Ions
8204	Wolf	Infrared Studies of Adsorption and Surface Dynamics During Heterogeneous Catalytic Reactions
8205	Wasan	Separation of Metal Ions by Accelerated Transport Through Liquid Surfactant Membranes

following which the Center Director will select projects for Year 03 support.

During Year 03, a research engineer, Dr. Dario Marani, from the Italian National Research Council will spend three months at IWERC, participating in the Centers research activities on metals speciation and separation.

One Year 03 proposed activity still under review is the establishment of an IWERC Industry Associates program, involving industry support of and cooperation with IWERC research. Should this program be implemented, it will constitute the first non-EPA funding to the Center. The concept and organizational structure have been reviewed and approved by the IAC. Approval by the Policy Board and the IWERC host institution, IIT, is still required.

YEAR 02 RESEARCH PROJECTS

The five research projects currently active at IWERC are abstracted in the following sections. Table 1 lists each project title and faculty principal investigator.

Project 8201

Adsorption/desorption technology has major potential for economical and selective recovery of valuable organic raw materials and products. However, scientific application of this technology requires a better understanding of the three key elements; isothermal equilibrium behavior, the solid-phase mass transfer coefficient and the effective diffusion coefficient. It is these three characteristics of a sorbate-sorbent system which define its potential performance and efficiency.

Adsorption in fixed-bed systems has been traditionally studied through outlet breakthrough curves interpreted using the mass transfer zone concept and continuity equations. The approach adopted in this study concentrates on the saturation history of the adsorbent particles within a differential-reactor. Mathematical models that describe adsorption involve the use of coupled partial differential equations with an integral equation and include two spatial variables and one temporal variable. The determination of the several controlling parameters is difficult and involves considerable laboratory and computational effort. The models proposed in this study include equations for mass transfer resistance and adsorption equilibria conditions in a differential-reactor. Parameters such as isothermal equilibrium constant, solid-phase mass transfer coefficient and effective diffusion coefficient are determined in the laboratory studies.

During the first year of this study a major part of the program has been directed toward the design, construction, and testing of laboratory experimental apparatus for sorption/desorption from both water and air streams. A one week workshop involving outside sorption experts has provided a critical review of the initial laboratory studies conducted on these test units. This group also reviewed the computer modeling developments and discussed future research plans.

The most important new information that has been obtained to date is the fact that the effective diffusivity as measured on the solid phase side is strongly concentration dependent. Present sorption models (based on measurements of the effective diffusivity on the liquid or gas phase side) assume D_r to be independent of concentration.

Project 8202

Wastewaters contaminated with metals originate as process streams from many industries, and remain one of the most vexing industrial effluents to manage economically and effectively. Such wastewaters are often difficult to treat, and typically generate hazardous sludges. This project, as well as Projects 8203 and 8205, is concerned with technologies to selectively recover metals from such wastewaters. The specific objective of Project 8202 is to study the kinetic and equilibrium limitations for the selective separation and recovery of metals using precipitation processes. The study has focused on the recovery of copper, trivalent chromium, nickel and lead to date, using as a model wastewater one typical of the electronics and printed circuit board industry. The study has recently identified waste age as a variable of major importance in the extent of precipitation achievable for chromium and lead. In addition, the experimental results indicate heretofore unsuspected interference in the precipitation of lead and copper, but a greater recovery efficiency than predicted for nickel.

With respect to the waste age factor, efficiency of chromium precipitation recovery dropped from near 100% for fresh wastes, to below 5% for process effluents aged for three weeks. A more rapid but less dramatic interference was observed for lead. Copper removal efficiency was unaffected by waste age, but was four-fold below that predicted. These results suggest that metals precipitation efficiency is strongly influenced by soluble phase kinetic and equilibrium limitations not previously identified in the pollution control literature.

Project 8203

The objectives of this project are:

- to investigate metal-ligand-sorbent systems representative of industrial wastes to determine conditions most favorable for separation and recovery.

- to develop a clearer understanding of the effects of speciation on adsorption-desorption reactions.

- to assemble the information obtained into a chemical model.
- to propose treatment schemes for application of the data.

It is well known that many industrial wastes contain mixtures of valuable inorganic components. In this research, methods for separating and recovering these waste products through adsorption onto various constant potential surfaces are explored. These surfaces have the advantages of being inexpensive and possessing a high density of surface complexing sites (for example one oxide of iron, α-FeOOH, has a surface site density of .14 moles/kg). Of importance is that the behavior of these sites toward the components to be recovered are a function of controllable (and adjustable) conditions in the solution phase. These controlling parameters can be grouped as follows:

Electrostatic charging of the surface
  -pH
  -degree of specific adsorption
  -ionic strength

Speciation of the ion
  -pH
  -oxidation-reduction potential
  -ionic strength
  -ligand or metal type and metal: ligand ratio

In addition, the reaction kinetics of the adsorption reactions tend to be rapid.

The systems investigated thus far in this research are shown in Table 2. Two surfaces have been used, α-FeOOH and γ-Al_2O_3. Several metal and ligand combinations broadly representative of industrial wastes are shown. The combinations of metals and ligands shown in Table 2 result in certain characteristics of the complex as summarized in Table 3. The charge and structure of the complex are two of the more important characteristics governing separation and removal.

Two examples of how these systems behave are presented: the first showing anion/cation separation and removal, the second showing

TABLE 2. SYSTEMS INVESTIGATED IN THIS RESEARCH

Cation	Anion	Surface(s)
H^+	OH^-	Fe, Al
H^+	CN^-	Fe, Al
H^+	CrO_4^{-2}	Fe, Al
Cd^{+2}	OH^-	Fe
Cd^{+2}	SO_4^{-2}	Fe
Cd^{+2}	CN^-	Fe
Cd^{+2}	Citrate	Fe
Cu^{+2}	OH^-	Fe
Cu^{+2}	CN^-	Fe
Ni^{+2}	OH^-	Fe, Al
Ni^{+2}	SO_4^{-2}	Fe
Ni^{+2}	NTA	Fe
Ni^{+2}	Glycine	Fe
Ni^{+2}	Citrate	Fe
Ni^{+2}	CN^-	Fe
Zn^{+2}	OH^-	Fe
Zn^{+2}	CN^-	Fe
Zn^{+2}	Citrate	Fe

TABLE 3. CHEMICAL PROPERTIES IMPARTED BY VARIOUS LIGANDS

LIGAND	CHARGE ON RESULTANT COMPLEXES	CHEMICAL STRUCTURE
SO_4^{-2}	usually neutral	ion pair
Citrate	usually negative	chelate, 6-, 5- member rings
NTA	negative	chelate, 5 member ring
Glycine	positive or neutral	chelate, 5 member ring
CN^-	positive, neutral or negative	square planar, tetrahedral, or linear

the separation and removal of two cationic species. For the former case, Figures 1 and 2 show the removal of Cd^{+2} and CrO_4^{-2}, respectively, on α-FeOOH. It is clear that the pH range of maximum Cd removal (7-9) largely excludes Cr(VI) and is quite distinct from the pH range of Cr(VI) removal pH (3-5). The second exampls is illustrated in Figures 3, 4 and 5 for Ni and Cd separation in the presence of cyanide. When no cyanide is present (Figure 3) the removal patterns of Ni and Cd are nearly identical. The addition of CN, first at ligand-metal ratios of about 1 (Figure 4)then at a ratio of approximately 10 (Figure 5), results in the separation of these two cationic species. The results can be explained in terms of the differential complexation of Ni and Cd by CN. An additional feature of the data shown in Figures 1-5 is that high recoveries can be achieved at relatively low concentrations of ionic species.

The feasibility of using these types of surfaces for the separation and recovery of dissolved waste components has been demonstrated. The underlying factors which control these reactions, namely charge effects (a measure of the entropy of these reactions), chemical bonding effects (as measured by the enthalpy of these reactions), and the role of species structure, have been investigated and are now understood to the degree that they can be used for predictive purposes.

Project 8204

Heterogeneous catalysts are used to increase the rate of chemical reactions, thus allowing operation at lower temperatures or with smaller equipment. Conversely, catalysts can be used to transform pollutants to environmentally acceptable species. Infrared Spectroscopy (IR) can be used to measure the concentration of species adsorbed on surfaces since their structure, and therefore their frequency for IR adsorption, is different from that in the gas phase. The objective of this work is to use Infrared Spectroscopy to study gas-surface interactions occurring during catalytic reactions involving gas phase pollutants.

The IR Spectrometer used in this project is a Fourier Transform Infrared (FTIR) Spectrometer which is characterized by its ability to obtain fast spectra, a high sensitivity and high resolution and computer data acquisition. The catalyst, in the form of a very thin wafer, which allows IR radiation to pass through, is placed in the reaction chamber. The IR cell-reactor permits in situ monitoring of both gas phase and surface concentration of the reaction gases.

An innovative new technique of Internal Reflection Spectroscopy (IRS) is now being evaluated to study catalyzed reactions in liquids.

EPA Form 2350-4 (4-80)
(PREVIOUSLY CIN. EPA FORM 257)
TYPING GUIDE SHEET

BEGIN FIRST LINE OF TEXT HERE
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD: BEGIN SECTIONS HERE
6 1/2"
9 1/8"

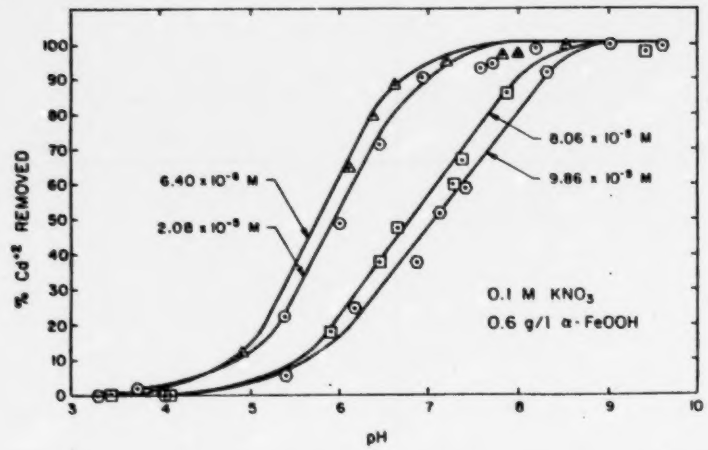


Figure 1. pH-Dependent Adsorption Edges for Various Concentrations of Cadmium on α-FeOOH.

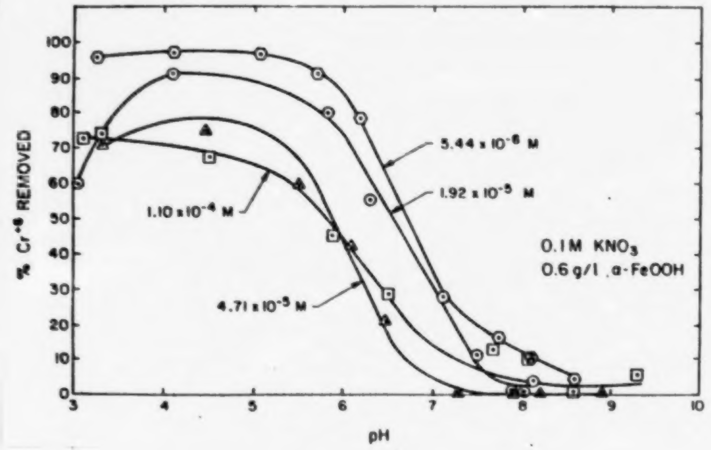


Figure 2. pH-Dependent Adsorption Edges for Various Concentrations of Cr(VI) on α-FeOOH.

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

PAGE NUMBER
EPA Form 2350-4 (4-80)
(PREVIOUSLY CIN. EPA FORM 287)
TYPING GUIDE SHEET

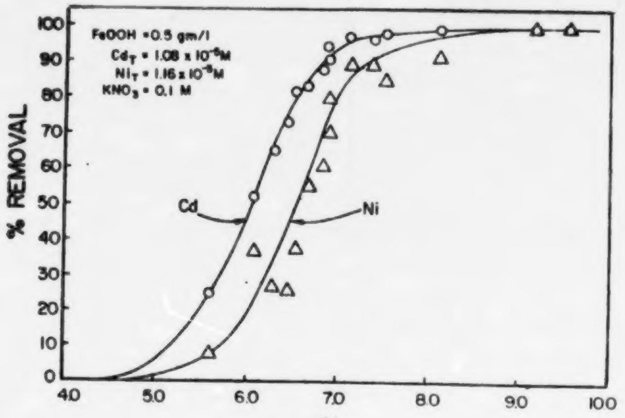


Figure 3. pH-Dependent Adsorption Edges for Cd and Ni on α-FeOOH.

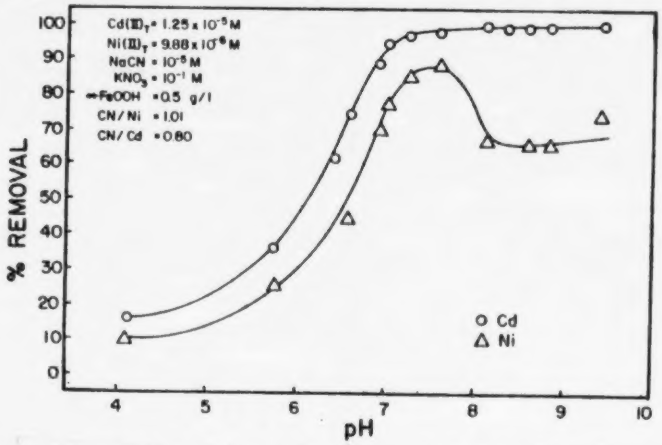


Figure 4. pH Adsorption Edges for Cd and Ni in the Presence of CN (CN/Me = 1).

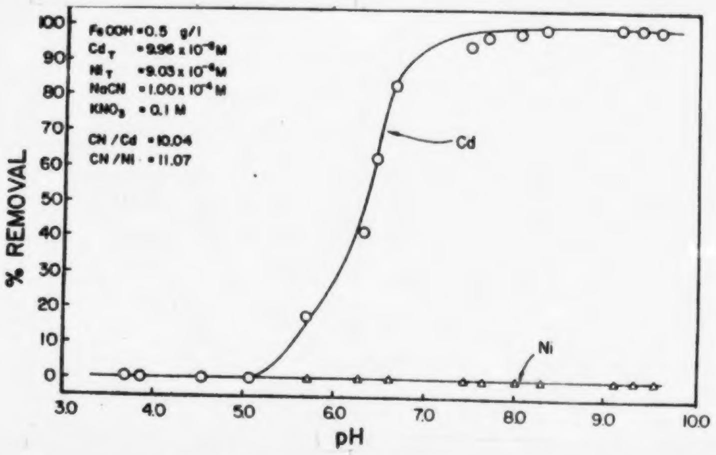


Figure 5. Cd and Ni Adsorption on α-FeOOH, Cn/Ni = 11.07, CN/Cd = 10.04.

IRS is believed to solve the problem of adsorption of IR radiation from the water or solvent phase, which prevents the use of transmission IR to study aqueous and other liquid behavior in catalyzed reactions.

Project 8205

Interest in the use of liquid membranes for metal ion recovery has grown rapidly in recent years. Application of metal-ligand systems, in conjunction with the facilitated transport through liquid surfactant membranes, to the ultimate goal of using ligands for the selective separation of metal ions from multiple metal aqueous solutions, has the potential to yield a high degree of separation; metal ions could be recovered economically, and from very dilute waste streams.

The concept of the liquid membrane system can be illustrated as follows. Two immiscible phases such as oil and water are blended to form an emulsion. The emulsion is then dispersed in a third phase (continuous phase) containing the metal ion species to be extracted. Upon mixing, many small globules of emulsion are formed. Normally, surfactant is added to the membrane phase for emulsion stability.

The project objectives are as follow:

1. To investigate metal-ligand-extractant-surfactant membrane systems and establish the conditions most favorable for metal ion recovery from wastewater.
2. To utilize the ligand accelerated transport mechanism as a means of greatly increasing metal cation fluxes and selectivities in liquid membrane process systems.

The particular system used for the initial study was a membrane phase composed of LOPS (a kerosene like hydrocarbon) as solvent (Viscosity = 2.6 cp; 5% v/v), 5% wt D2EHPA (Di-2-ethylhexyl phosphoric acid) as extractant and 4% wt ECA 4360 (Exxon polyamine) as surfactant. The internal phase of the emulsion was a 50-200 g/ℓ H_2SO_4 solution which served as a stripping agent. The external aqueous phase of the liquid membrane system was $CoSO_4$ solution containing 1000 ppm Co^{+2} containing 0.1 mole sodium acetate (NaAc) as ligand. The experimental procedure consisted of mixing a 50 mℓ solution of the internal aqueous phase with a 50 mℓ solution of membrane phase in a Waring Blender for about 5 minutes at the ambient temperature. The liquid membrane emulsion (20-40 mℓ) was then added to a 400 mℓ beaker containing 200 mℓ $CoSO_4$ solution to be extracted.

BEGIN FIRST LINE OF TEXT HERE
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD BEGIN SECTIONS HERE
BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
EPA Form 2350-4 (4-80)
(PREVIOUSLY CIN. EPA FORM 287)
TYPING GUIDE SHEET

The system was stirred by a variable speed mixer equipped with a marine-type impeller. Mixing speed ranged from 150-300 rpm. Samples of the feed solution were taken periodically and analyzed with a UV spectrophotometer for cobalt concentration. The results are shown in Figure 6 for a treat ratio, $V_{ext}.phase/V_{emulsion} = 5$ (volume of external aqueous phase divided by volume of emulsion). These results, which show an extraction efficiency of 98% within 2 minutes, are very encouraging in that the extraction efficiency is enhanced by the presence of a ligand such as acetate, and also that the pH remained constant. However, in the absence of acetate, the pH of the external aqueous phase changed continuously and the efficiency was 80%. This was caused by emulsion instability which resulted in membrane leakage.

The effects of kinetics of extraction of different ligands in the external phase is shown in Figure 7. These results show that among the ligands tested, acetate demonstrates the ligand effect most dramatically (90% extraction in 2 minutes for 0.1m acetate). Figure 7 also shows data for the case where there is no ligand present in the feed solution. It is evident from this figure that the presence of a ligand enhances the extraction efficiency.

Having determined that acetate is a favorable ligand for the extraction of cobalt, the kinetics and efficiency of cobalt extraction as a function of acetate concentration in the continuous aqueous phase were studied and the results are shown in Figure 8. These results show that there exists an optimum acetate concentration (0.1m) for the maximum recovery of Co^{+2} from the aqueous phase. This may be attributed to the fact that the increase of ligand concentration favors the thermodynamic equilibrium for transforming kinetically inert hydrate metal ions into labile ligand-metal complex.

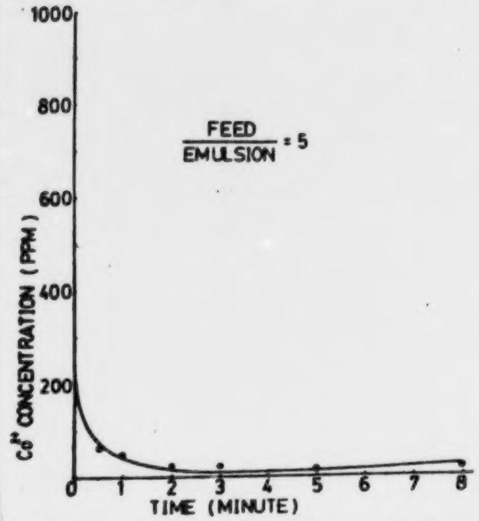


Figure 6. Extraction of Co^{2+} from 1000 PPM Co SO_4 Solution into 50 G/L H_2SO_4 Solution.

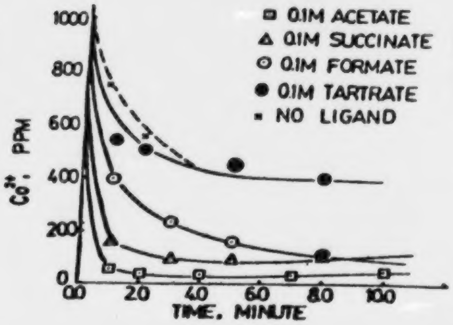


Figure 7. Effects on Kinetics of Extraction of Different Ligands in External Phase.

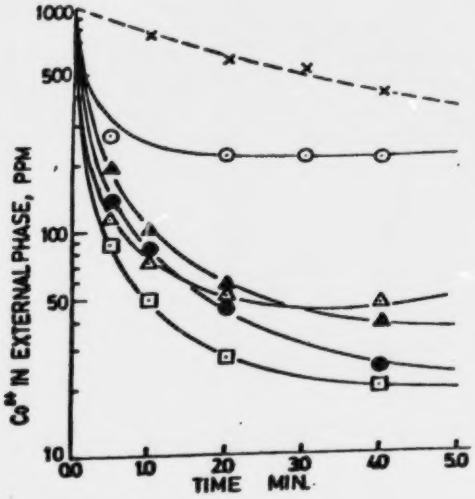


Figure 8. Effect on Kinetics of Extraction of Acetate Concentration in External Phase (x No Acetate, ⊙ 0.05M, △ 0.075M, ⊡ 0.10M, ● 0.15M, ▲ 0.20M).

The work described in this paper was not funded by the U.S. Environmental Protection Agency. The contents do not necessarily reflect the views of the Agency and no official endoresement should be inferred.

CHROMIUM REMOVAL MECHANISMS FOR WASTE MANAGEMENT OF A SPECIALTY STEEL MILL

VIRGINIA M. CUSANO
and
ROBERT H. WILLS, JR.
CRUCIBLE INC., SYRACUSE, N.Y.

ABSTRACT

The Resource Conservation and Recovery Act along with recent rounds of State Pollution Discharge Elimination System permits reflecting the application of Best Available Technology Economically Achievable have significantly increased costs for transportation, treatment and disposal of both solid and liquid wastes. In addition, the New York State Superfund places an assessment on certain wastes.

Crucible Specialty Metals Division in Syracuse, New York has been involved in various resource recovery projects since 1975. These projects include:

1. Investigation of the effectiveness of an abandoned alkaline wastebed to absorb and retain Chrome and other heavy metals present in steel mill wastes.
2. A method of detoxification of hazardous air pollution baghouse dusts by transferring soluble chrome from the solid phase to the liquid phase for recycle or treatment.
3. Reuse of waste acid, from our pickling operations, as the primary coagulant at Crucible's Industrial wastewater treatment plant.

Crucible Specialty Metals is a specialty steel mill located on a 75 acre site in Syracuse, New York. One thousand (1000) tons of stainless, tool, high speed, valve, alloy and super alloy are produced per week. The main markets for the products are the aerospace, automotive and machining industries.

Melting operations utilize EAF's (electric arc furnaces). In 1906 Crucible started the first and only electric arc furnace in the Western hemisphere. A twenty two (22) and thirty five (35) ton EAF are now in use. High grade scrap and alloying materials are charged into the furnaces along with slagging agents. When the initial melt is done, the molten steel is transferred to a thirty five (35) ton Argon Oxygen Decarburization vessel (AOD) for refining.

Crucible also has a Vacuum Melting department consisting of Vacuum Arc Remelting (VAR) and Crucible Particle Metallurgy (CPM) processes. The VAR furnace uses a metal electrode (poured in the Melt Shop) and remelts the steel using high direct current and vacuum to remove impurities. The CPM process uses an induction furnace to remelt high speed steel. The molten steel is then poured through an atomizer where water or nitrogen quenches it, forming micro ingots. The micro ingots are heated to compaction in an autoclave.

Cogging operations consist of a 2000 Ton Davy press and 26" two-high reversing mill which reduces the large ingots into billets.

The Rod and Bar Mill consists of a 18" two high reversing mill for roughing, 3 stands of 14" Mill for intermediate reduction, 2 stands of 12" Mill for bar finishing and a 10" vertical stand and 7 stands of 9" Mill for wire products. The North Rolling Mills consist of 14", 12-2 and 9" jobbing hand rolling mills.

The North Hammer Shop uses 2,000, 4,000 and 8,000 pound steam hammers to provide a good hot finished surface on the steel.

Conditioning consists of grinding and pickling operations. Mechanical grinders and hand operated swing frame grinders use abrasive wheels to remove the ingot skin and any other major surface defects. Pickling is utilized to chemically remove mill scale and to impart a satisfactory finish on the product. Pickling solutions include muriatic acid, sulfuric acid, nitric hydrofluoric acid, potassium permanganate, molten caustic, suspended lime and various coating solutions.

Bar Finish operations include straightening, grit blasting, lathe turning, grinding, machining, cold draw, sawing, inspection and shipping.

Waste streams from these various operations are similar in volume and basic pollutants to any other steel mill, however, since Crucible makes 400 grades of specialty steel, more "specialty" pollutants (e.g. Cr, Ni, W, etc.) and less "poor quality" scrap pollutants (e.g. Pb, Zn, etc.) are seen. The 400 grades produced also lead to variability within the waste streams.

Typical waste stream analysis for solid wastes are presented in Table 1, for leachables from solid waste in Table 2, and for liquid wastes entering the waste water treatment plant in Table 3.

Of specific concern is the parameter Cr^{+6} (Hexavalent chromium) due to its toxic and soluble nature. Cr^{+6} is present in EAF baghouse dust and AOD baghouse dust, as a result of the high temperatures and oxidation that occurs during melting and refining. Cr^{+6} is also generated in the molten caustic tanks. The chrome from the mill scale and the product are oxidized into the hexavalent state. The Cr^{+6} is not a problem per se while in the solid waste form, but, becomes a major problem when water is leached through the material.

The solid wastes generated at the mill are landfilled on top of an abandoned alkaline waste bed. The waste bed contains 60 feet of waste material from the Solvay Process production of soda ash ($Na_2 CO_3$). The alkaline nature of the waste bed, along with its homogeneity and adsorptive capacity make it a unique repository for metallic wastes. Ground water analysis from various levels both in and under the waste bed show non detectable levels of metals (including Cr^{+6}) from the steel making wastes which have been deposited there over the past 9 years. Metals which are leached by rain water are adsorbed and retained in the top layer of the Solvay Process waste.

EAF and AOD dusts have not been deposited at our landfill since March 3, 1982 and are now being recycled for recovery of nickle and chrome units.

Prior to recycling, a method for detoxification of EAF and AOD dusts was developed (See figure 1). The basic philosophy is to transfer the hazardous component (Cr^{+6}) from the solid phase to the liquid phase with subsequent treatment or reuse. The resulting wet dust would not contain any hazardous leachable components (as defined by RCRA) and could be disposed of in a sanitary landfill.

The detoxification process involves a leach tank and high shear mixer to thoroughly wet the dust. The dilution ratio is 5 (total mixture weight) to 1 (solids weight).

The solvent used will be dependent on the anticipated final use of the liquid:

EPA Form 2350-4 (4-80)
(PREVIOUSLY 2IN, EPA FORM 233)
TYPING GUIDE SHEET

TABLE 1

COMPOSITION OF CRUCIBLE WASTES

mg/Kg or ppm

Wastes	Parameters											
	ALK	Al	As	Cd	CN	Cr(T)	Cu	Fe	Pb	Hg	Ni	Zn
A) Non-Hazardous Wastes												
Coolant Swarf (Krasney)	62	590	3.0	100	0.04	50,000	5520	136,000	10	0.04	NA	19
WWTP Sludge	930	2,000	5.0	48	0.04	10,800	660	92,000	280	0.2	3,340	460
Slag	400	13,400	2.0	38	0.15	6,400	89	29,000	30	0.04	2,560	40
Mill Scale	12	210	10	70	0.04	1,380	1840	58,600	2.0	0.04	16,000	18
Boiler House Ashes	48	2,000	2.0	1.2	0.04	47	33	111,000	2.0	0.04	48	17
Grinding Dust	20	290	7.5	8.1	0.004	60,800	3360	500,000	18	0.04	25,000	21
Coolant Swarf, South Wire Mill	94	120	5.0	71	0.04	26,000	47	166,000	4	0.04	11,800	50
B) Hazardous Wastes												
Air Pollution and AOD Dust	1600	4000	7.0	74	0.40	6,600	840	100,000	2600	0.6	4,200	5000
Waste Caustic Solids	6000	120	7.0	8.0	2.75	7,200	75	8,600	2	0.04	336	7.0

TABLE 2. EP TOXICITY TEST LEACHATE RESULTS

Wastes	Parameters (mg/l)							
	Arsenic	Barium	Cadmium	Total Chromium	Lead	Mercury	Selenium	Silver
Detection Limits	0.002	1.0	0.01	0.01	0.02	0.002	0.002	0.01
A) Non-Hazardous Wastes								
WWTP Sludge	LT .002	LT 1.0	0.05	LT 0.01	0.18	LT .002	LT .002	LT .01
Slag	LT .002	LT 1.0	0.01	0.02	0.16	LT .002	0.022	LT .01
Mill Scale	LT .002	LT 1.0	0.20	0.15	0.08	LT .002	LT .002	LT .01
Boiler House Ashes	LT .002	LT 1.0	0.01	0.30	0.08	LT .002	LT .002	LT .01
Grinding Dust	LT .002	LT 1.0	0.11	0.33	0.02	LT .002	LT .002	LT .01
Coolant Swarf, South Wire Mill	LT .002	LT 1.0	0.04	1.70	0.10	LT .002	LT .002	LT .01
Excavated Soil Material	LT .002	LT 1.0	0.10	0.09	0.48	LT .002	LT .002	0.03
B) Hazardous Wastes								
Air Pollution Dusts	LT .002	LT 1.0	1.59	56	0.08	0.03	0.012	0.01
AOD Dust	LT .002	LT 1.0	0.33	LT 28	0.16	LT .002	0.024	LT .01
Waste Caustic Solids	0.007	LT 1.0	0.04	LT 126	0.26	.002	0.008	LT .01
RCRA Limiting Concentrations	5.0	100	1.0	5.0	5.0	0.2	1.0	5.0

BEGIN FIRST LINE OF TEXT HERE
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD BEGIN SECTIONS HERE

TABLE 3. SUMMARY OF AVERAGE DAILY CONTAMINANT POUNDAGES
TANK A INFLUENT
(POUNDS PER 4-HOUR PERIOD)

Parameter	Average Value 4-days	Highest Daily Average Value	Lowest Daily Average Value	Ratio Variability
TSS	606	1451	94	15.4
TOC	112	226	27	8.4
Cyanides-Total	1.42	2.60	0.79	3.3
Cyanides-Oxid.	0.087	0.21	0.007	30.0
Nitrate	132	175	7.0	2.5
Sulfate	3803	5647	2104	2.7
Chloride	665	811	401	2.0
Cadmium-Total	ND	ND	ND	0
Cadmium-Soluble	ND	ND	ND	0
Chromium-Hex.	1.09	2.18	0.024	90.8
Chromium-Total	26	66.0	1.3	50.8
Chromium-Soluble	5.4	17.0	0.1	170
Copper-Total	3.6	6.6	0.4	16.5
Copper-Soluble	0.6	1.12	0.08	14.0
Iron-Total	172.5	495	20.0	24.7
Iron-Soluble	25.6	100	0.4	250
Zinc-Total	4.0	7.1	1.84	3.9
Zinc-Soluble	1.86	3.5	0.6	5.8
Fluoride	90	111	63.0	1.8

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS

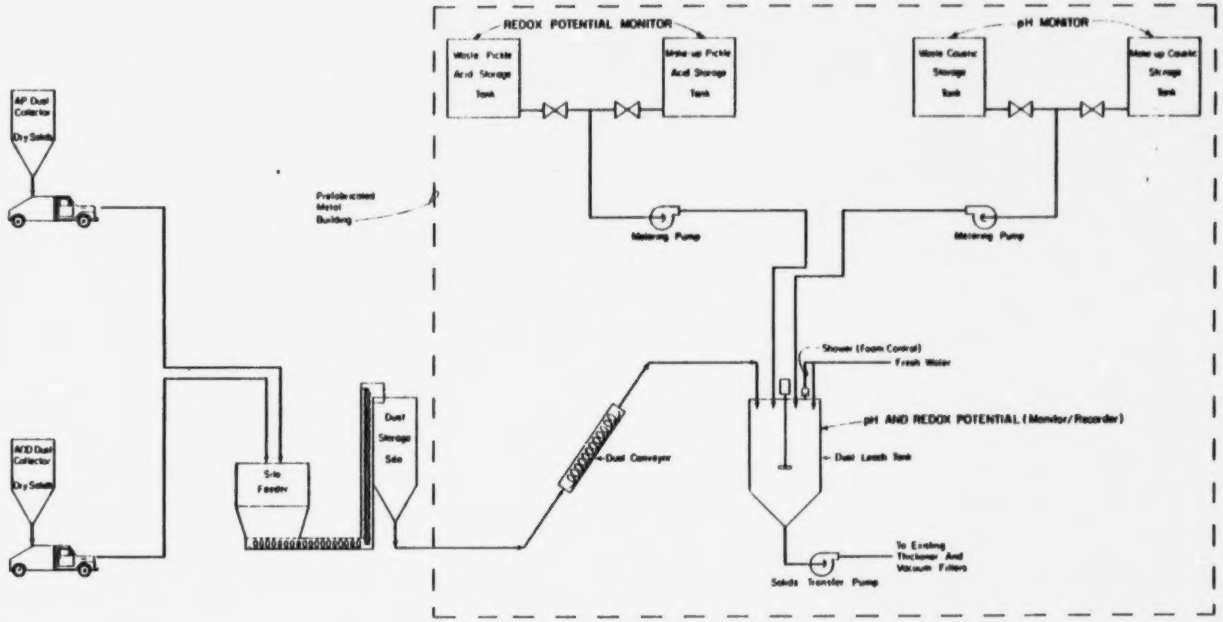

AP Dust Collector
Dry Solids
AOD Dust Collector
Dry Solids
Prefabricated Metal Building
Silo Feeder
Dust Storage Silo
Dust Conveyor
REDOX POTENTIAL MONITOR
Waste Pickle Acid Storage Tank
Make-up Pickle Acid Storage Tank
Metering Pump
pH MONITOR
Waste Caustic Storage Tank
Make-up Caustic Storage Tank
Metering Pump
Shower (Foam Control)
Fresh Water
pH AND REDOX POTENTIAL (Monitor/Recorder)
Dust Leach Tank
Solids Transfer Pump
To Existing Thickener And Vacuum Filters

Figure 1. Proposed Detoxification of EAF and AOD Dusts.

1. If the process is used for recyling, water will be the solvent. The resulting chromate solution has potential for use as a corrosion inhibitor, for sale to a chrome plater, or for chrome recovery via electro winning or other processes.

2. If the process is used strictly for detoxifying the dusts, a water and acid mixture will be the solvent used to increase the leaching and initiate treatment of the chromate. The actual chromate reduction is discussed later in this report.

The resultant wet dust can be pumped to a sludge and vacuum filter or be disposed of directly, depending on the solids content.

Chromate can enter the waste water at pickle lines by drag out, carryover, or during normal rinsing and quenching operations. The chromate enters the waste stream in slugs due to the batch type operation. This accounts for the large variability ratio as shown in Table 3.

Crucible's industrial waste water (4.5 MGD) is collected at three main pumpstations ranging in flow capacity from 200 gpm to 3800 gpm (See Figure 2). The waste water is pumped to the aeration tank where:

1. It is blended
2. Gross pH adjustment occurs
3. $FeSO_4$ (ferrous sulfate) is added

The waste water flows by gravity to a 120 foot diameter primary clarifier where:

1. pH is controlled at 7.6
2. .6 ppm of a highly anionic polymer is added
3. $FeSO_4$ is added as the primary coagulant and to insure proper chromate reduction

87% (3.9 MGD) of the clarified water flows into a wet well and is recycled back to the mill for reuse. The remaining 13% (.6 MGD) flows to a secondary clarifier where:

1. pH is adjusted to 8.2
2. .6 ppm of a highly anionic polymer is added

Sludge from both clarifiers is pumped to a sludge thickener and then to two 8 foot diameter vacuum filters.

Hexavalent Chrome may be removed from waste water by any of the four processes:

1. electrochemical reduction followed by chemical precipitation
2. Ion exchange
3. Dissolved air flotation

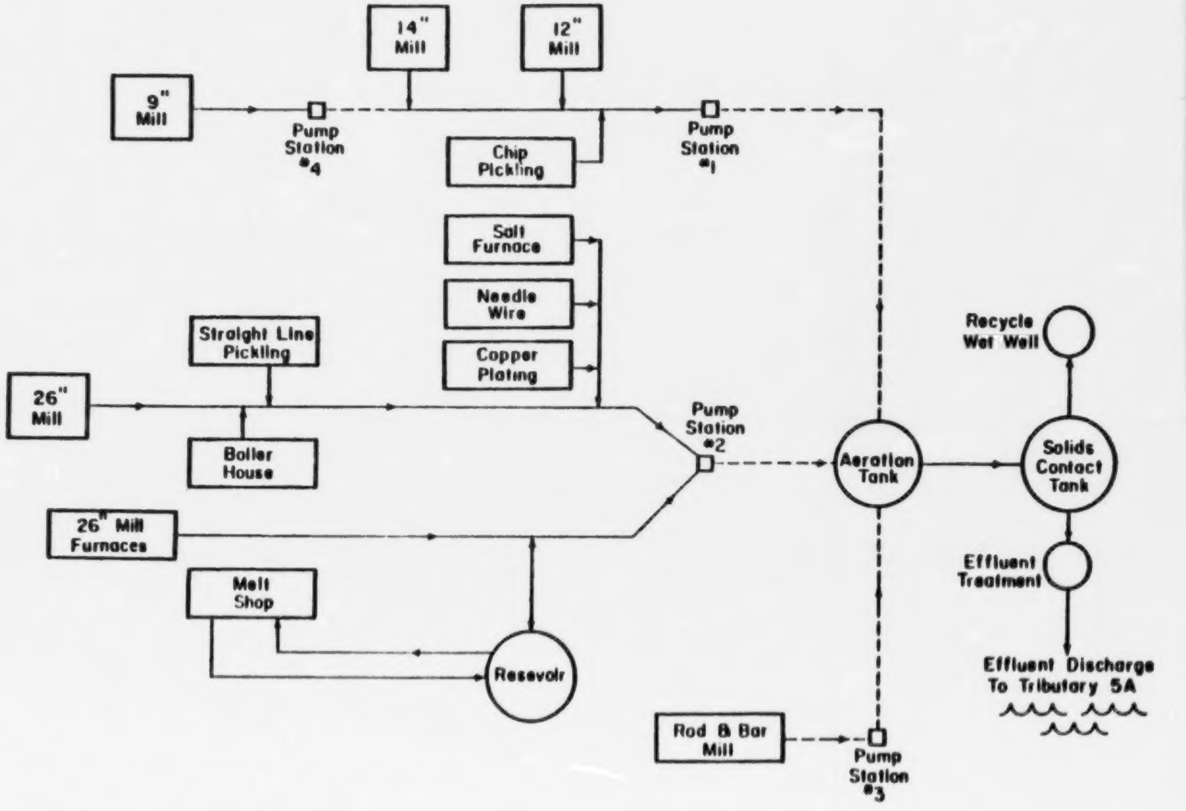

9" Mill
Pump Station #4
14" Mill
12" Mill
Chip Pickling
Pump Station #1
Salt Furnace
Needle Wire
Copper Plating
Straight Line Pickling
26" Mill
Boiler House
Pump Station #2
26" Mill Furnaces
Melt Shop
Resevoir
Rod & Bar Mill
Pump Station #3
Aeration Tank
Solids Contact Tank
Recycle Wet Well
Effluent Treatment
Effluent Discharge To Tributary 5A

Figure 2. Schematic of Crucible's Industrial Wastewater Flow.

EPA Form 2350-4 (4-80)
(PREVIOUSLY CIS EPA FORM 231)
TYPING GUIDE SHEET

4. chemical reduction followed by chemical precipitation

Electrochemical reduction processes rely on electrolytic production of ferrous iron to initiate hexavalent chrome reduction. Since a ready supply of ferrous iron is available in waste pickling acids, electrochemical reduction processes are unnecessary and would be expensive.

Ion-exchange is a hex-chrome removal technique used for waste streams containing no metal species other than chromium, such as cooling water blowdown. Presence of other metals in the Crucible waste stream makes use of Ion-exchange impossible.

Dissolved-air ion flotation is a removal process whereby a cationic surfactant is added to hex-chrome bearing water forming a surface active complex which exists as a collodial suspension. This suspension is floated to the surface by air bubbles, forming a froth which is aggregated by polymer additions and drawn off for disposal.

Both Ion-exchange and dissolved-air Ion flotation remove hex-chrome without reduction and would leave a disposal problem of uncertain magnitude and severity.

Hexavalent chrome may be removed from the waste stream by chemical reduction of the hex-chrome to trivalent chrome and eventual precipitation of the trivalent chrome as the hydroxide.

Reduction may be carried out using SO_2 or the Sulfite/bisulfate sodium salts, or with ferrous iron (Fe^{+2}). Chemical precipitation of triavalent chrome as the hydroxide may be done with caustic soda or lime. Since Crucible has an available supply of ferrous iron in the form of waste pickling acids and presently uses caustic soda, the ferrous reduction/caustic precipitation method is the most cost effective and logical treatment scheme.

Hexavalent chromium is actually present in waste waters in the form of oxyanions chromate (CrO_4^{-2}) or dichromate ($Cr_2O_7^{-2}$). The proposed redox reaction with ferrous iron would proceed according to the equation:

$CrO_4^{-2} + 8H^+ + 3Fe^{+2} \rightarrow Cr^{+3} + 4H_2O + 3Fe^{+3}$ and has a redox potential of +.56 volts indicating an energetically favorable couple with three moles of ferrous iron reducing one mole of chromium.

Laboratory testing demonstrated that a 5:1 molar ratio of Fe^{+2}: Cr^{+6} resulted in optimum chromium reduction.

Crucible's Pickle lines generate both waste sulfuric (H_2SO_4) and waste muriatic acids (HCl). Both acids were studied to determine their capacity for hex-chrome reduction, and both proved equally effective. However, spent sulfuric acids constitute a larger volume and a more readily available ferrous source, and therefore are more often used as the reducing agent.

Testing also demonstrated that the ferrous/chromate redox reaction is essentially complete in one minute with both H_2SO_4 and HCl waste pickle liquors. (see Table 4, 1 through 6). The redox reaction also appears to proceed independent of pH, with chrome reduction evidenced from pH 3 to pH 10.

Tests 7 through 9 were done to evaluate the stability of the reduced and precipitated chromium to wide pH fluctuations and are also reported in Table 4. The precipitate was digested with NaOH resulting in final pH of 10.9 and no increase in soluble chrome. Digestion of the precipitate with HCl to a final pH of 2.0 also produced no increase in soluble hex-chrome, but did show considerable soluble trivalent chrome. Precipitation of chrome with caustic under automatic pH control guarantees low pH resolubilization of trivalent chrome.

Waste Water Treatment Plant influent was sampled and analyzed at the aeration tank in an effort to quantify mean hex-chrome concentrations. Analysis of data showed a range of hex-chrome from .006 mg/l to 4.65 mg/l with a mean concentration of 1.39 mg/l. Estimates to compute spent acid requirements used an average volume of 4.5 mgd of water being processed and a ferrous iron concentration of 5 x 1.4 mg/l = 7.0 mg/l required to reduce the chrome. Using spent H2SO4 with a ferrous iron strength measured at 63,400 mg/l waste sulfuric acid requirements are calculated to be 500 gallons /day maximum. This level of usage is equivalent to the upper limit established for Ferric Chloride, the primary coagulant originally used at the WWTP. Ferrous iron (Fe^{+2}) oxidized to ferric iron (Fe^{+3}) in the chrome reduction process may now be used as a primary coagulant as well as a Hex-chrome reducing agent.

A Ferrous Sulfate solution of approximately 3% Fe^{+2} is metered to the aeration tank.

Pumping rates are established according to approximate flow rates and an assumed Cr^{+6} influx of 2.0 mg/l. Ferrous Sulfate is metered to maintain a 5:1 molar ratio of Fe^{+2}: Cr^{+6}. Automatic pH control establishes required pumping rates for caustic soda with a target pH of 7.2 as a goal before discharge to the primary clarifier (SCTA).

pH is automatically adjusted in SCTA to 7.6 using ferrous sulfate and caustic soda as the reagents. A high molecular weight organic polyelectrolyte is also added to SCTA to assist in the flocculation of the waste water. This polymer is anionic in nature, and appears to work synergistically with the ferrous sulfate resulting in improved coagulation.

Approximately 87% of the effluent from SCTA is recycled back to the mill and requires no further processing. The remaining 13% of the flow is routed to the secondary clarifier (SCTB). 15% H_2SO_4 acid, anionic

TABLE 4

LABORATORY RESULTS FOR HEX-CHROME REDUCTIONS

Test #	REACTANTS CAUSTIC RINSE Cr-tot (mg/l)	 Cr^{+6} (mg/l)	 ACID PICKLE LIQUOR Fe^{+2} (mg/l)		MIXTURE MOLAR RATIO $Fe^{+2}:Cr^{+6}$	pH ADJUSTMENTS	PRODUCTS Fe-tot (mg/l)	 Cr-tot (mg/l)	 Cr^{+6} (mg/l)
1	50.5	50.5	H_2SO_4	25,000	5:1	4.0 - 1 min. contact		3.0	0.1
2	50.5	50.5	H_2SO_4	25,000	5:1	4.0 - 15 min. contact		4.0	0.1
3	50.5	50.5	H_2SO_4	25,000	5:1	5.0 - 90 min. contact		.22	0.1
4	50.5	50.5	HCl	42,000	5:1	9.4 - 1 min. contact		.01	0.1
5	50.5	50.5	HCl	42,000	5:1	9.4 - 15 min. contact		.01	0.1
6	50.5	50.5	HCL	42,000	5:1	9.8 - 90 min. contact		.02	0.1
7	50.5	50.5	HCl	42,000	5:1	9.4 - no adjustment	.60	.01	0.1
8	-	-	(ppt. filtered and digested .01N NAOH)			10.9 - no adjustment	1.77	.35	0.1
9	-	-	(ppt. filtered and digested .01N HCl)			2.0 - no adjustement	46	11.7	0.1

polymer, and caustic solution are metered and final effluent is automatically maintained at a pH of 8.2. This base adjustment in pH is insurance for complete removal of trivalent chromium as a metal hydroxide.

This reduction/precipitation removal mechanism for chromium is characterized by indisputable economic benefits:

1. Elimination of transportation and disposal charges for spent acid
2. Reduction of tax liabilities (State Superfund on disposal of wastes)
3. Reduction of chemical costs at the Waste Water Treatment plant (complete elimination of $FeCl_3$ as the primary coagulant)
4. Improved overall treatment
5. A decrease in future, capital spending for additional pollution abatement devices.

The use of spent acids have the additional capacity of reducing toxic hexavalent chromium from EAF and AOD dusts, thus diminishing a potential solid waste problem should recovery of metals from these dusts prove uneconomical.

The work described in this paper was not funded by the USEPA. The contents do not necessarily reflect the views of the agency and no official endorsement should be inferred.

LANDFILLING SOLID WASTES FROM SPECIALTY STEEL PRODUCTION ON A SOLVAY PROCESS WASTEBED

J. A. Hagarman, Ph.D., R. W. Klippel, P.E.
Calocerinos & Spina, Consulting Engineers
and R. H. Wills, Jr., Crucible, Incorporated

ABSTRACT

For the past eight years, Crucible, Incorporated, Specialty Metals Division in Syracuse, New York has been landfilling solid wastes from production of specialty steels on an abandoned Solvay Process wastebed adjacent to Onondaga Lake.

The hydrogeology and geochemistry of the site, as well as the leaching chemistry of landfilled solid wastes, have been studied intensively over the past several years in order to define potential problems such as contamination of areal groundwater and surface water and impacts on the local biological community.

The results of these studies show that the Crucible landfill does not pollute either ground or surface waters and has no harmful effects on biota. Studies of Electric Arc Furnace (EAF) and Argon-Oxygen Decarburization (AOD) dusts indicate a high leaching potential for toxic hexavalent chromium. Detailed studies of the interaction of hexavalent Cr leached from EAF and AOD dusts and the Solvay Process waste underlying the landfill show that two attenuation mechanisms immobilize the hexavalent Cr in the underlying Solvay Process waste.

The operation of this landfill is presently permitted by the New York State Department of Environmental Conservation under Part 360 of the State Rules and Regulations as a non-hazardous solid waste management facility. The five-year operating permit specifies that no air pollution dust or other toxic waste will be landfilled at the site. An eight-foot lift of waste is planned, producing a ten-year lifetime for the facility. A quarterly inspection and monitoring plan and requirements for closure cover and surface runoff control are specified in the permit. Liner and leachate collection systems are not required for the present landfill, but could be necessary for future expansions of the site.

INTRODUCTION

State and Federal regulations governing waste disposal have required the Iron and Steel Industry to determine the hazardous nature of all wastes, to keep close account of hazardous wastes from source to ultimate disposal and to treat or dispose of hazardous wastes in an environmentally safe manner. Implementation of these regulations leaves industry accountable for past disposal practices and will make industry responsible for adverse impacts from present or future waste disposal.

In the case of Crucible Incorporated, Specialty Metals Division in Syracuse, New York, Department of Environmental Conservation regulations require permitting of landfills for disposal of both hazardous and non-hazardous solid wastes. The New York State regulations equal or exceed Federal regulations for disposal of hazardous wastes.

Crucible has been landfilling solid wastes on an abandoned Solvay Process wastebed adjacent to Onondaga Lake for the past nine years. As a result of a two-year study of the chemistry, hydrogeology and structural stability of the landfill, the continued operation of this site has been permitted by the State as a non-hazardous solid waste management facility.

SOLVAY PROCESS WASTE

Solvay Process began producing soda ash in the Syracuse area in 1884 because of the abundant supply of raw materials including limestone, salt and process water. Waste solids from the production were landfilled from 1916 to 1950 in a swampy lowland adjacent to the western shore of Onondaga Lake. The lakeside Solvay Process wastebed eventually comprised 364 acres filled to a maximum height of 60 feet. To construct the wastebeds, a waste slurry was transported to the area by pipeline, confined in sections by hand-dug dikes and allowed to drain. Segments of the total area were abandoned at several elevations resulting in a terraced structure surrounding the central plateau which is the site of the Crucible landfill.

Solvay Process waste is composed of a mix of insoluble oxides and silicates, alkaline hydroxides which buffer the groundwater at pH 11, carbonates and soluble chloride salts which produce high salinity in the wastebed groundwater.* The silty wastes, when drained and settled, assume a moist, cake-like consistency with numerous cemented layers containing flyash. Salt content of the wastebed surface decreases by leaching several years after placement allowing development of a sparse but diverse vegetation including alkali-tolerant weeds, grasses and woody species, predominantly willows and poplars. The waste remains nutrient-deficient, largely in phosphorus. Fertilization results in marked increases in density of vegetative cover.

CRUCIBLE SOLID WASTES

The Crucible landfill presently occupies 17 acres of the lakeside Solvay Process wastebed with a maximum fill height of 5 feet. Types of waste landfilled, average annual volumes and results of Extraction Procedure Toxicity testing are shown in Table 1.

TABLE 1. CRUCIBLE SOLID WASTES

Specific Waste	Annual Quantity cu. yd.	Classification	Hazardous Parameters	Current Disposition
Currently Landfilled Wastes				
Slag	6,290	Non-Hazardous	None	Landfill
Construction Debris & Refractories	4,104			
Boiler House Ashes	1,437			
Coolant Swarf	1,375			
Mill Scale	1,121			
WWTP Sludge	165			
Total	14,492			
Previously Landfilled Wastes				
Grinding Dusts	688	Non-Hazardous	None	Recycled & Reused
Air Pollution & AOD Dusts	1,176	Hazardous	Chromium & Cadmium	Recycled & Reused
Waste Caustic Solids	200	Hazardous	Chromium	CECOS Int'l
Acid Pickling Solids	50	Hazardous	Chromium	On-Site Treatment
Total	2,114			

---

* C.S. Grove, Jr., et al, The Rehabilitation of Solvay Process Wastebeds, Bureau of Solid Waste Management, Environmental Control Administration, Public Health Service, Department of Health, Education and Welfare, Grant Number 5-R01-U1-00537-02, Dec. 1, 1969.

Slag, boiler house ash, swarf, scale and wastewater treatment plant sludge are non-hazardous wastes which comprise 63% of the total landfilling volume. Slag is a mineral residue generated during melting of scrap metal and added alloys in electric arc furnaces. Boiler house ash is a mixture of flyash and bottom ash produced by combustion of coal for generation of steam. Metal finishing processes, such as grinding, produce a swarf consisting of abrasive and metallic particles and waste coolant. Scale is a metallic oxide coating which develops on metal surfaces during heating and cooling and is removed by machining. Wastewater treatment plant sludge is coagulated and dewatered solids removed from wastewater by a two-stage, in-plant treatment process. Air pollution dust is collected by baghouses from both the Electric Arc Furnaces (EAF) and an Argon-Oxygen Decarburization (AOD) Vessel. This material is hazardous due largely to the content of soluble, toxic hexavalent Chromium. In addition to testing by the Extraction Procedure Toxicity Test, leaching studies by both column and successive batch procedures give a hexavalent Chromium content of approximately 430 mg. per kg. dry dust. Because of the toxic leaching potential of air pollution dusts landfilled from 1973 in the case of EAF dust and from 1977 for AOD dust, a geotechnical and chemical study of the Crucible landfill was initiated. The general objective of this study was to determine the impact of the Crucible landfill on groundwater quality in the area. Specifically, the fate of soluble, toxic hexavalent Chromium contained in air pollution dusts was to be determined. In addition, landfilling of air pollution dust was discontinued in March of 1982. Dusts are presently being recycled for recovery of Chromium and Nickel.

GEOTECHNICAL AND CHEMICAL STUDIES

The geotechnical study was performed by Thomsen Associates and their affiliate Empire Soils Investigations, Incorporated. The objectives of this study were to:

- sample deposits in the area including landfilled Crucible wastes, Solvay Process waste and underlying natural deposits,
- define subsurface conditions and the hydrogeolic regime at the site,
- install a groundwater monitoring system to determine impact of the Crucible landfill on groundwater quality and
- evaluate stability and settlement characteristics of the lakeside wastebed relative to the Crucible landfilling activities.

In order to accomplish these objectives, 43 borings were advanced into the wastebed using a machine-driven 3-1/4 inch hollow-stem auger. Soil samples were retrieved from 25 of these borings using a split-barrel sampler. Soil samples were photographed and retained for classification and chemical analysis. While the majority of these borings penetrated Solvay Process wastes, three were advanced into natural deposits under the wastebed with a maximum depth of 167 feet. Deposits underlying Solvay Process waste generally consist of swamp deposits, lacustrine silts and alluviodeltaic deposits over glaciolacustrine silts and sand. Depths and types of deposits vary with location, but beneath the Crucible site organic deposits average 11 to 15 feet in thickness.

Boreholes were converted into multiple piezometers, 2 inch monitoring wells or lysimeters to obtain groundwater surface measurements and water quality samples. Detail of groundwater monitors is shown on Figure 1.

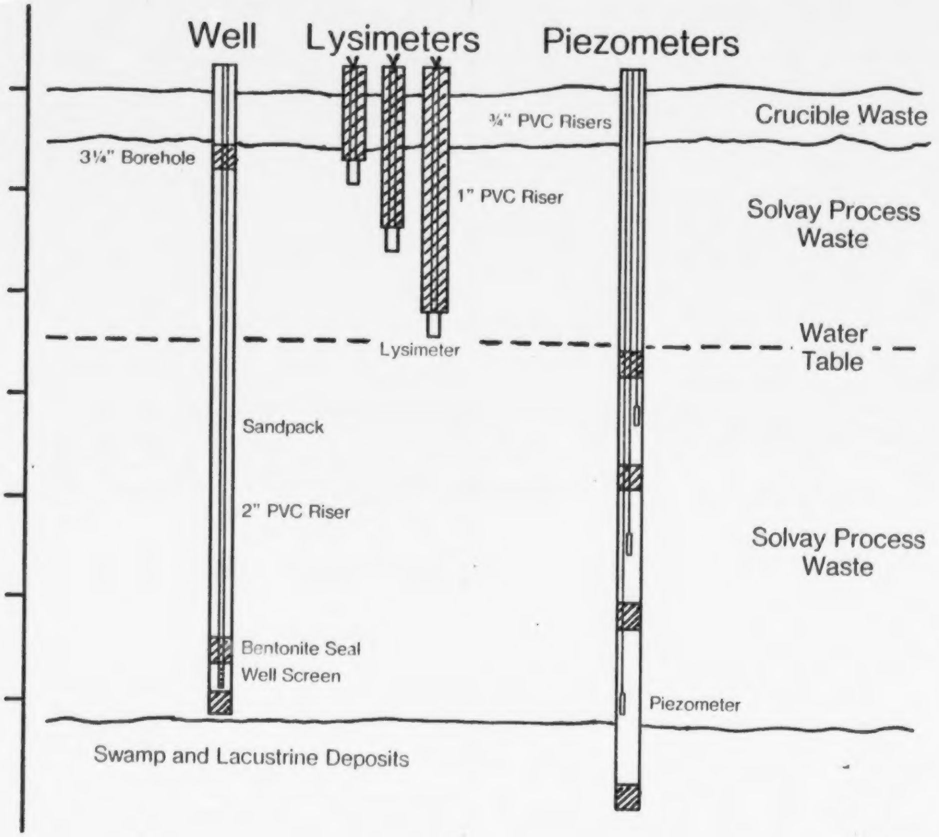

Well
Lysimeters
Piezometers
0
10
20
30
40
50
60
Crucible Waste
¾" PVC Risers
3¼" Borehole
1" PVC Riser
Solvay Process Waste
Water Table
Lysimeter
Sandpack
2" PVC Riser
Solvay Process Waste
Bentonite Seal
Well Screen
Piezometer
Swamp and Lacustrine Deposits

FIGURE 1. DETAIL OF GROUNDWATER MONITORS

Locations of these monitors are shown in Figure 2.

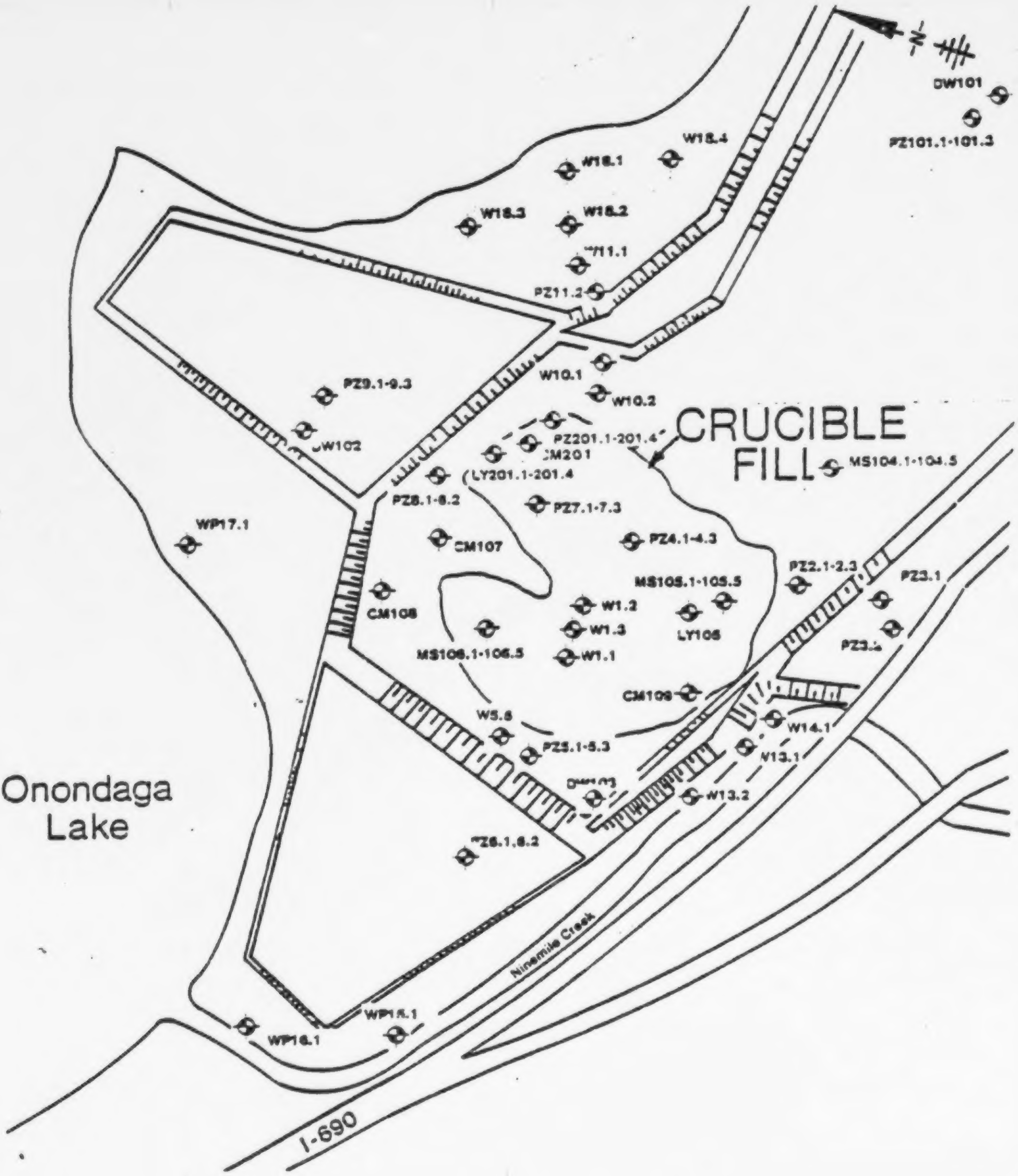

N
DW101
PZ101.1-101.3
W15.4
W15.1
W15.3
W15.2
W11.1
PZ11.2
W10.1
W10.2
PZ9.1-9.3
DW102
CRUCIBLE FILL
PZ201.1-201.4
CM201
LY201.1-201.4
MS104.1-104.5
PZ8.1-8.2
PZ7.1-7.3
WP17.1
CM107
PZ4.1-4.3
PZ2.1-2.3
PZ3.1
MS105.1-105.5
CM108
W1.2
W1.3
LY105
PZ3.2
MS106.1-106.5
W1.1
CM109
W5.5
PZ5.1-5.3
W14.1
W13.1
DW103
W13.2
Onondaga Lake
PZ6.1,6.2
Ninemile Creek
WP15.1
WP16.1
I-690

FIGURE 2. GROUNDWATER MONITORING LOCATIONS

EPA Form 2360-4 (4-80)
(PREVIOUSLY EIN. EPA FORM 261)
TYPING GUIDE SHEET

A total of 62 monitors were utilized to investigate the groundwater flow regime. A large groundwater mound was found to exist in the Solvay Process waste beneath the Crucible landfill. Results of a series of 30 field and laboratory hydraulic conductivity measurements on the various geologic units at the site are consistent with a pattern of slow vertical movement of groundwater through Solvay Process waste and the swamp/lacustrine layer into underlying deposits. In underlying deposits, downward movement is restricted and groundwater flows laterally to surface waters of Nine Mile Creek and Onondaga Lake. Flow rates in the Solvay Process waste are calculated to be approximately 30 ft./yr., in the swamp/lacustrine deposits less than 10 ft./yr. and in underlying deposits as high as 310 ft./yr.

A three-dimensional mathematical model of the groundwater flow regime at the site was developed using a United States Geological Survey computer program. The model simulates groundwater recharge and movement using estimates of infiltration from rainfall and snowmelt and hydraulic conductivity from field and laboratory measurements. The calibrated model closely correlates with groundwater surface data obtained from the monitor system and predicts 23 inches of infiltration annually through the Crucible waste and 9 inches through the Solvay waste. These infiltration amounts produce a total annual leachate volume for the Crucible waste of approximately 10 million gallons. This leachate is diluted by approximately 30 million gallons of groundwater in underlying alluvial and glaciolacustrine deposits prior to discharge to surface waters.

Analyses of groundwater samples from the 41 monitoring wells (Figure 2) over the past two years show high pH (11) and dissolved solids (mostly Sodium, Calcium and Chloride) within the Solvay Process waste due to the alkaline and saline nature of the waste. The Chromium concentration in groundwater samples is consistently below the detection limit of the Atomic Absorption technique (.01 mg./L.) which is below State groundwater standards (.05 mg./L.). The only groundwater influence attributible to the Crucible landfill is a low level of Iron and Manganese typically below the State groundwater standard of .3 mg./L.

During the late winter/early spring snowmelt period, numerous seeps develop near the base of the Solvay Process wastebed as the groundwater mound rises due to high recharge. A series of five seepage galleries were installed in areas of heavy seep flows as part of the geotechnical project. Location of these monitors is shown in Figure 3. Analyses of these five seeps, as well as other smaller seepage areas, also show Chromium concentrations below the detection limit of .01 mg./L. From these analyses of well and seep samples, it is evident that the soluble hexavalent Chromium contained in landfilled air pollution dusts has not reached the groundwater regime in detectible concentrations in the nine years of operation of the landfill.

In order to determine the fate of this potential pollutant, a series of four lysimeters were installed in an area of the Crucible landfill known to contain fresh ($<$ 1 year) air pollution dust. This location is shown as Ly 201 on Figure 2. The lysimeters were installed at six-foot intervals

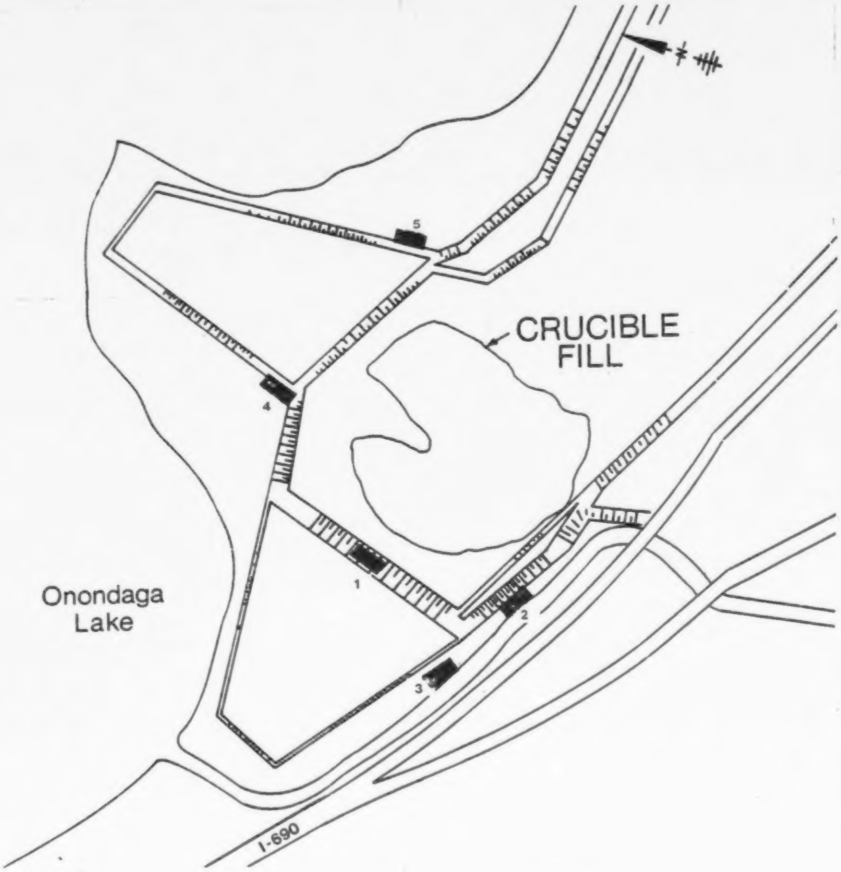


FIGURE 3. SEEPAGE GALLERY LOCATIONS

in the unsaturated zone of the Solvay Process waste directly beneath the fresh air pollution dust. A vacuum is placed on the sampler overnight to draw pore water into the sampler. The sample is then retrived by pressure the following day. Analyses of samples from this monitor system showed high concentrations of hexavalent Chromium (approximately 1,000 mg./L.) in the surface lysimeter directly under the Crucible landfill but Chromium below detection limits in deeper lysimeters.

A series of twelve test pits were also dug with a backhoe around the edge of the Crucible landfill both in areas of air pollution dust deposits and in areas with no dusts. The location of these pits is shown in Figure 4.

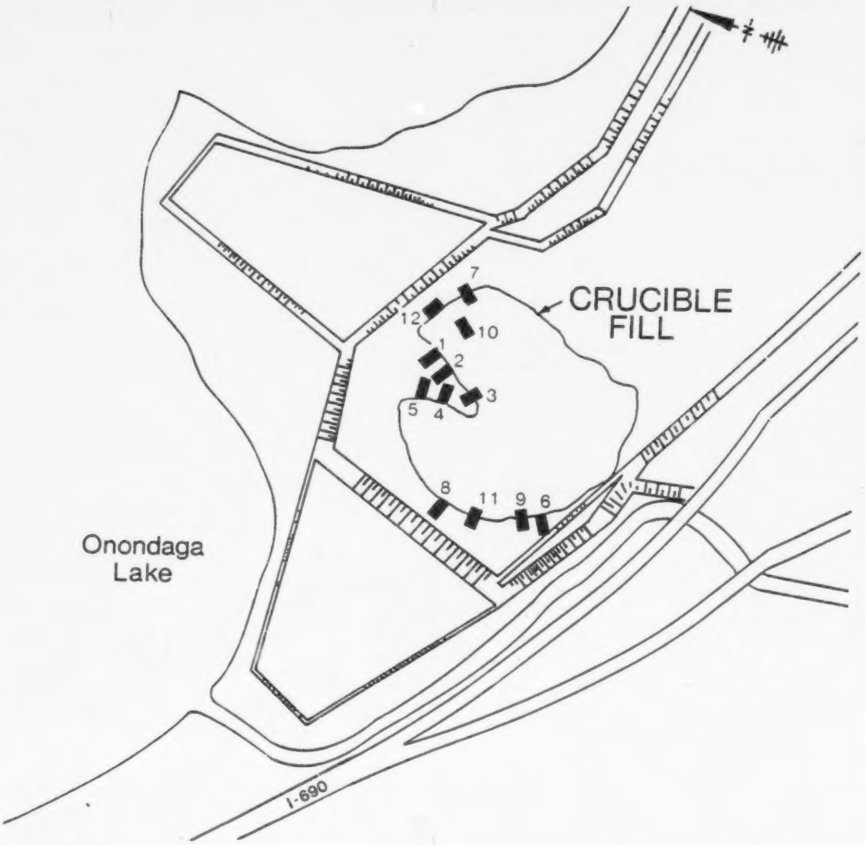


FIGURE 4. TEST PIT LOCATIONS

In each case where air pollution dust was landfilled, a yellow stain was observed in the surface of the Solvay Process waste immediately under the dust. Analyses of this yellow stain showed high levels (to 500 ppm) of hexavalent Chromium adsorbed to the Solvay Process waste. Comparison of the extent of migration of the stain to the age of the dust deposits reveals that the soluble hexavalent Chromium is leached from the air pollution dust within one year of landfilling and is contained in the top six feet of Solvay Process waste within three years. No further migration of the Chromium is evident up to five years after landfilling. The complete monitoring system installed in the fresh air pollution dust deposits is shown in Figure 5.

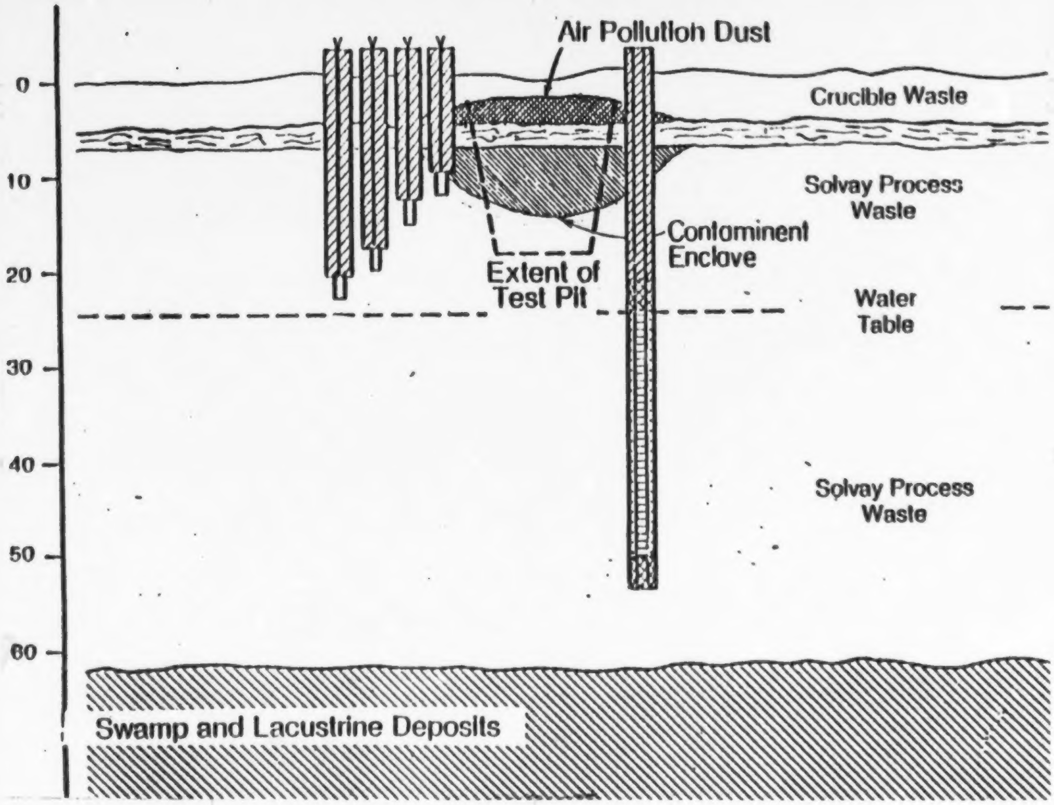

Air Pollution Dust
0
10
20
30
40
50
60
Crucible Waste
Solvay Process Waste
Contaminent Enclave
Extent of Test Pit
Water Table
Solvay Process Waste
Swamp and Lacustrine Deposits

FIGURE 5. FRESH AIR POLLUTION DUST MONITORING SYSTEM

The partitioning of hexavalent Chromium between groundwater and Solvay Process waste has been studied in our laboratory by measuring the adsorption isotherm for Solvay Process waste samples taken from the surface of the wastebed, the bottom of a test pit and at a depth of 23 feet. In all cases, a linear isotherm was obtained with distribution coefficients of 2.9 ml./g. for the surface sample, 5.2 ml./g. for the test pit sample and 7.4 ml./g. for the sample from 23 feet in the wastebed. The adsorption maximum of 5,300 mg./kg. for the deep Solvay Process waste may be compared to values of 670 mg./kg. for montmorillonite clay and 190 mg./kg. for kaolinite clay as determined by Griffen in similar tests.* The stains found in the test pits are examples of "contaminant enclaves" which are stable with finite pollutant sources such as the air pollution dust deposits. Solvay Process waste immobilizes the hexavalent Chromium much more efficiently than an equivalent layer of clay typically used as a landfill liner.

---

* Griffen et al, Effect of pH on Adsorption of Chromium From Landfill-Leachate by Clay Minerals, J. Environ. Sci. Health, A12(8), 431-449 (1977)

Analysis of metal content in samples of Solvay Process waste taken from borings at the landfill reveals low levels of reduced, precipitated non-toxic Chromium in the vicinity of the groundwater table beneath the Crucible landfill. No Chromium was found in samples taken from borings off the Crucible landfill. The samples containing Chromium also showed high levels of Iron relative to the rest of the Solvay Process waste samples taken both under and off the Crucible landfill. Beyond the contaminant enclaves identified in test pits an extensive zone of very low concentrations of soluble hexavalent Chromium could slowly transfer very low levels of Chromium from the enclaves to the water table. This transfer would be accentuated during late winter and early spring when high recharge of the aquifer occurs. At the water table, very low concentrations of hexavalent Chromium could be reduced and precipitated by redox coupling with soluble Iron in the groundwater.

The impact of leachate from the Crucible landfill on the waters of Onondaga Lake has been estimated by calculation of daily groundwater loads of trace metals. As a percentage of total loads to the Lake, groundwater loads from the Crucible landfill are negligible.

Analysis of the strength and structural stability of the Solvay Process wastebed relative to the Crucible landfill included in situ vane shear and torvane tests, laboratory unconfined compression tests and consolidation tests. Slope stability analyses indicate an acceptible factor of safety for a 10 foot lift of Crucible waste with an edge setback of 100 feet. Maximum settlement with a 10 foot Crucible lift was estimated to be 5 feet resulting in a dish-shaped surface which will promote containment of surface runoff and downward percolation of infiltrated water.

PRESENT STATUS AND FUTURE OPERATING PLANS

Crucible is presently operating the landfill under a five-year permit from the New York State Department of Environmental Conservation as a non-hazardous solid waste disposal facility. No air pollution dust or other hazardous wastes will be landfilled at the site.

As part of the operation permit, a quarterly landfill inspection and groundwater sampling and analysis program have been developed. Water samples from selected wells, seeps and lysimeters will be closely monitored to insure that hexavalent Chromium concentrations at the water table do not exceed State groundwater standards and to further document the secondary redox control of soluble Chromium by Iron. Neither daily nor intermediate cover will be required prior to closure of the present site. A maximum lift of ten feet of waste is permitted, producing a lifetime for the present landfill of ten years. Details of closure of the present landfill and requirements for liner, leachate collection and cover for a future expansion area are presently under deliberation by the State.

Although the research described in this paper has been funded wholly or in part by the U.S. Environmental Protection Agency, it has not been subjected to Agency review and therefore does not necessarily reflect the views of the Agency and no official endorsement should be inferred.

PARTICULATE AND PARTICLE SIZE DATA FOR CLEAN AND CONTAMINATED QUENCH WATER USAGE - DOFASCO NO. 1 WET COKE QUENCH TOWER

by: John D. Jeffery
GCA Corporation/Technology Division

ABSTRACT

A measurement program was developed in cooperation with EPA's offices of Stationary Compliance (SCCD), Research and Development (ORD-RTP), and Industrial Research (IERL-RTP), Dominion Foundries and Steel Company, Ltd. (DOFASCO), and the Munters Company to sample emissions from the No. 1 wet Coke Quench Tower located at DOFASCO's facility in Hamilton, Ontario. The tower, its location, baffle design and availability of both clean and contaminated water for quenching was selected to answer areas of concern for the co-sponsors. Briefly, these areas are: Can a tower, equipped with a multiple directional baffle array located in the upper two-thirds of the tower with an exit velocity less than 20 fps achieve lower emission rates than towers previously tested? What removal efficiency can be achieved, and what will the particle size distribution be?

The program sampling was devised to measure particulate matter and particle size distribution above and below the baffle array simultaneously. The tower was sampled during normal operations with quench water at 501 mg/l and later with by product flushing liquor at 8850 mg/l TDS. Composite water samples were taken from the quench water header line, the return trough and the varying make-up supply lines for each particulate test conducted to determine the effect of water quality on emissions. Process observations were recorded pertaining to battery operations, coal-coke conditions, and the operation of the Quench tower itself.

INTRODUCTION

A sampling program co-sponsored by IERL, ESED and SCCD was conducted to develop emission factors for the No. 1 coke quench tower at Dominion Foundries and Steel, Limited (DOFASCO), Hamilton, Ontario, Canada. Additional support and funding was provided by DOFASCO and The Munters Company. These emission factors will be used in the data base for the Inhalable Particulate Program, NSPS and enforcement/compliance considerations pertaining to wet coke quenching. Total particulate and particle size distribution tests were conducted simultaneously before and after the baffle array controlling quenching emissions. Water samples were taken during each particulate test at the quench, return and make-up lines, as was process data for each quench tested. Additional tests were conducted for organic compounds, and condensible matter.

Five particulate tests were performed during "clean" quench water (510 mg/l total dissolved solids)usage. Three particulate tests were conducted at the outlet only with "semi-dirty" quench water (2270 mg/l total dissolved solids) in use and four tests were conducted during "dirty" quench water (8850 mg/l total dissolved solids) usage.

PROCESS DESCRIPTION

QUENCH TOWER

The No. 1 quench tower, located approximately 60 feet from the southern end of battery No. 1, serves batteries Nos. 1, 2 and 3. The tower is constructed of stainless steel and is rectangular in shape measuring approximately 50 ft x 20 ft x 51 ft. Figure 1 illustrates the baffle and sampling locations. A total of 87 spray nozzles, arranged in three rows of 29, are used to deliver quench water to the incandescent coke. These spray nozzles are located approximately 18 feet above the quench car tracks. The total quenching cycle, from the time the hot car was completely in the tower to the time completely out, was observed to average 2.4 minutes.

The baffles are plastic Munters T-271 mist eliminators, installed approximately 12 ft from the top of the tower. The T-271 is composed of a series of multiangular shaped separating walls arranged to provide a channel for the gas flow. Figure 2 shows the gas/droplet flow through one of the channels of the T-271 mist eliminators. A high pressure sequential spraying system was installed above the baffles to remove particle buildup. Water for this system is taken from the Hamilton Harbor/bay and is used as part of the makeup water.

The No. 1 quench tower was considered and selected by the co-sponsors of this program due to several important factors. These are:

- Invitation by DOFASCO to test,
- Scaffolding, ports and general access to be provided by DOFASCO,
- Anticipated high efficiency of the baffle system,
- Sampling access above and below the baffles without requiring modifications, and
- Availability of both "clean" and "dirty" make-up water sources.

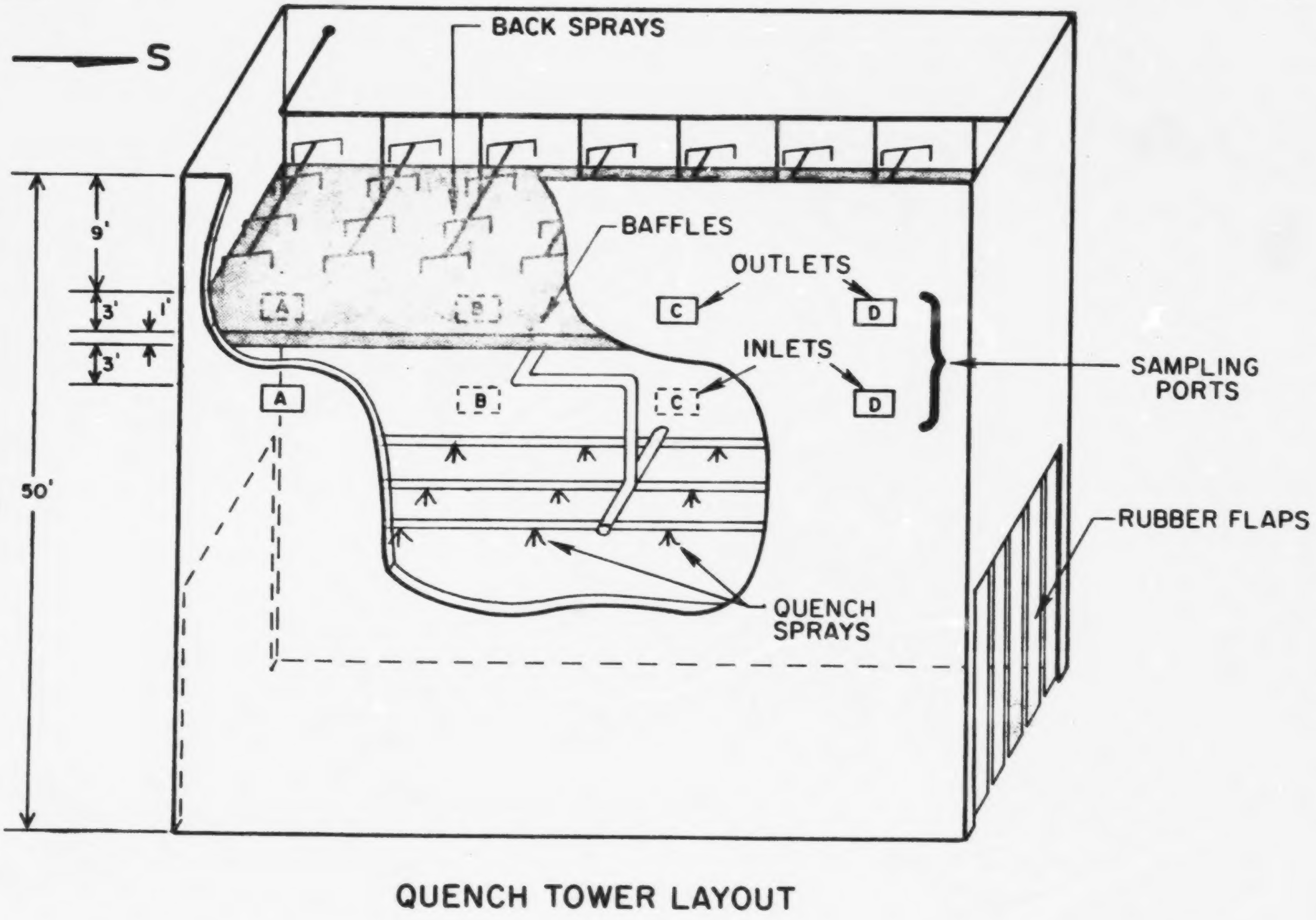
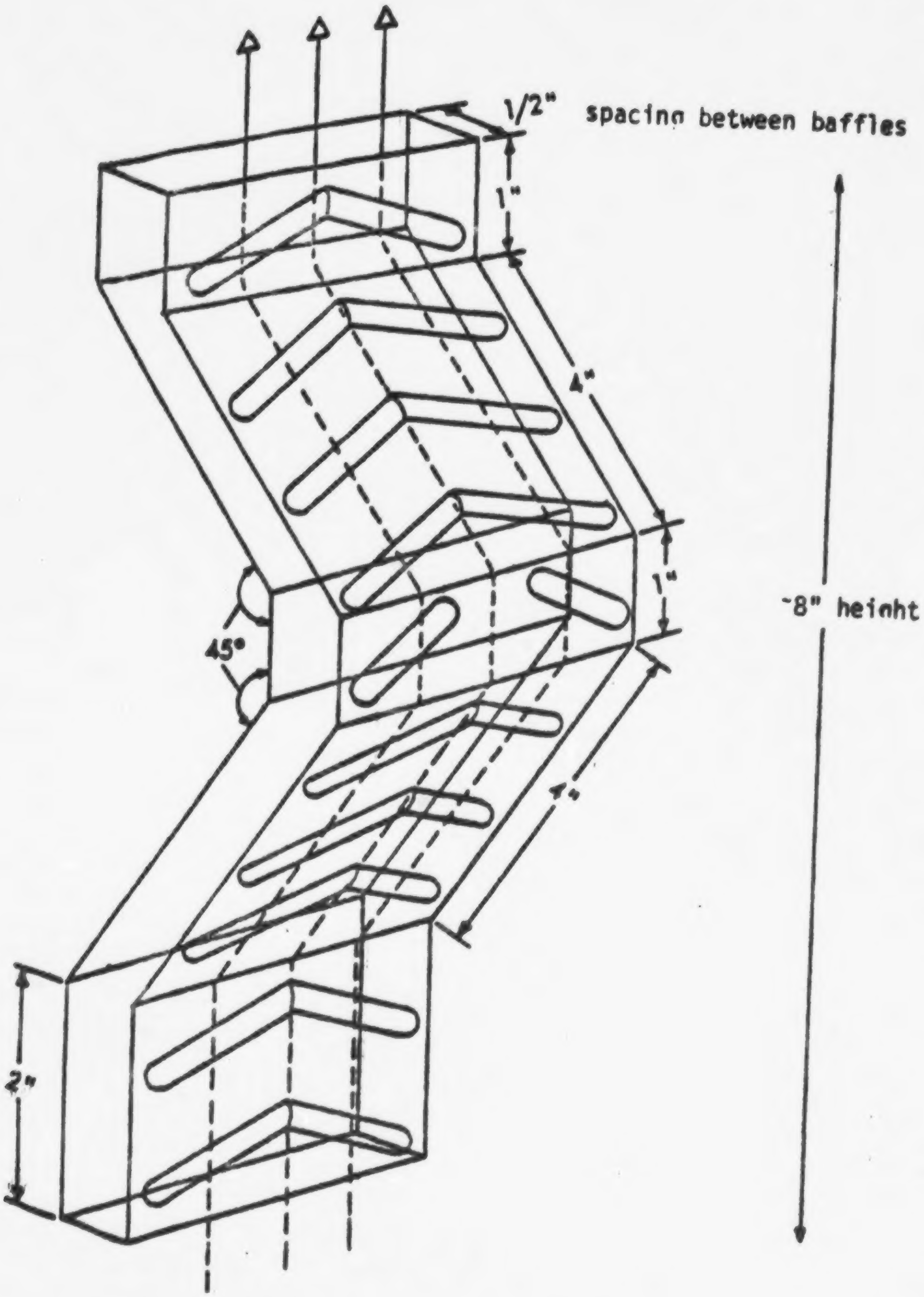

S
BACK SPRAYS
BAFFLES
OUTLETS
C
D
INLETS
C
D
SAMPLING PORTS
A
B
A
B
RUBBER FLAPS
QUENCH SPRAYS
9'
3'
1'
3'
50'
QUENCH TOWER LAYOUT

Figure 1. Quench Tower Layout.

BEGIN FIRST LINE OF TEXT HERE
CENTER OF
TOP OF IMAGE
DROPPED HEAD: BEGIN SECTIONS HERE


1/2" spacing between baffles
1"
4"
1"
~8" height
45°
4"
2"

----▷ indicates air flow between baffles

Figure 2. Side view of gas flow through baffle channel.

TEST METHODS

TOTAL PARTICULATE MATTER

Total particulate matter sampling was conducted simultaneously above and below the baffle array with a Hi-volume Aerotherm sample train to minimize the amount of time required to collect a sufficient volume of gas and weight of particulate matter (see Figure 3). In order to allow a more accurate determination of moisture in the stack gas, to prevent filter plugging, and to provide a rough indication of particle sizing, a cyclone designed to have a 50 percent cut size of about 3 microns at the anticipated flow rate was used. A continuous strip chart recorder was connected to a Hastings/Raydist meter to record the gas velocity pressure (Δp) and to aid in verifying any uneven flow patterns.

TEST SEQUENCE

A preliminary traverse was used to establish the rate (length of time) of rise in velocity pressure (Δp), the maximum Δp, and the rate of decline of Δp to an end point greater than zero. For each quench, the sampling rate, ΔH was gradually increased from the signal CAR-IN for approximately thirty (30) seconds. The maximum sampling rate was maintained until the signal WATER-OFF was given and a ramp down procedure was initiated to a predetermined rate established from the averaging of the ramp down portion of the velocity profile. Sampling was then terminated when the car was completely out of the tower. An example of the velocity profiles obtained during testing is shown in Figure 4.

Due to physical obstructions (i.e., ladders, monorail guidewires, etc.), it was necessary to sample only two (2) ports per test. Therefore, two (2) quenches were sampled at each sample point until twelve quenches were sampled, or in the case of some of the tests, nine quenches due to weather or process conditions.

ANDERSEN IMPACTOR SAMPLING

Particle size distribution in the 0.8 to 15 micron range was determined using heated Andersen Mark III cascade impactors, preceded by cyclone precollectors. The in-stack fractionating sampler provides eight size range measurements. The SORI cyclone IX precutter removed particles greater than approximately 15 microns. The determination of impactor stage cutpoints and particle size distribution was performed using the interactive PADRE computer data reduction system. Testing was conducted simultaneously above and below the baffle array at the same port and point.

WATER SAMPLING

Water samples were taken at three locations representing three phases of water during the quenching process. Samples were taken at the inlet to the quench sprays ("Quench water"), the return to the sump after quenching (Return water"), and at the makeup to the sump ("Make-up water") which was bay water

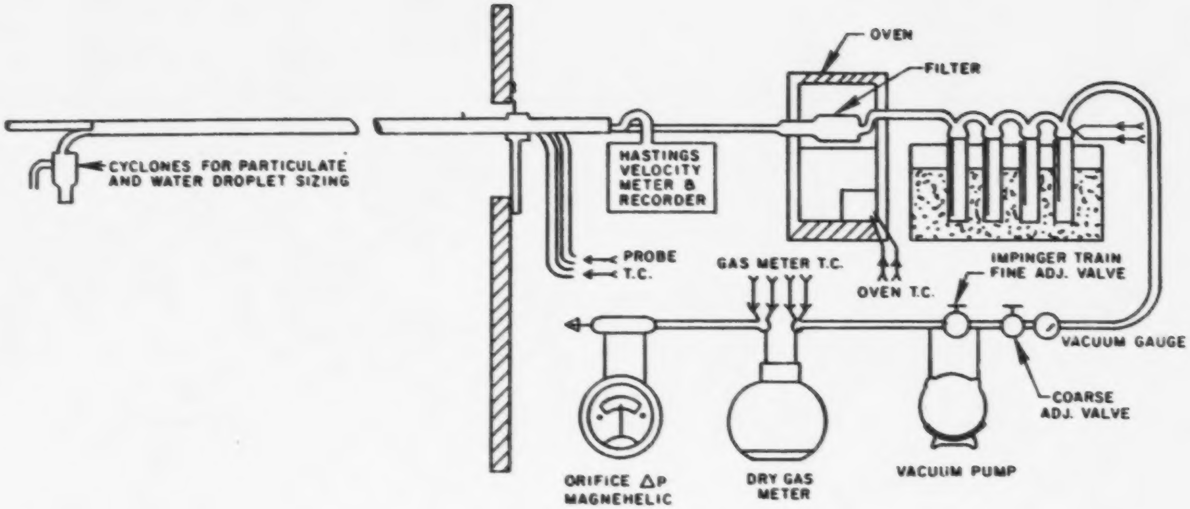

OVEN
FILTER
CYCLONES FOR PARTICULATE AND WATER DROPLET SIZING
HASTINGS VELOCITY METER & RECORDER
PROBE T.C.
GAS METER T.C.
OVEN T.C.
IMPINGER TRAIN FINE ADJ. VALVE
VACUUM GAUGE
COARSE ADJ. VALVE
ORIFICE ΔP MAGNEHELIC
DRY GAS METER
VACUUM PUMP

Figure 3. Schematic drawing of Hindome Particulate Sampler.

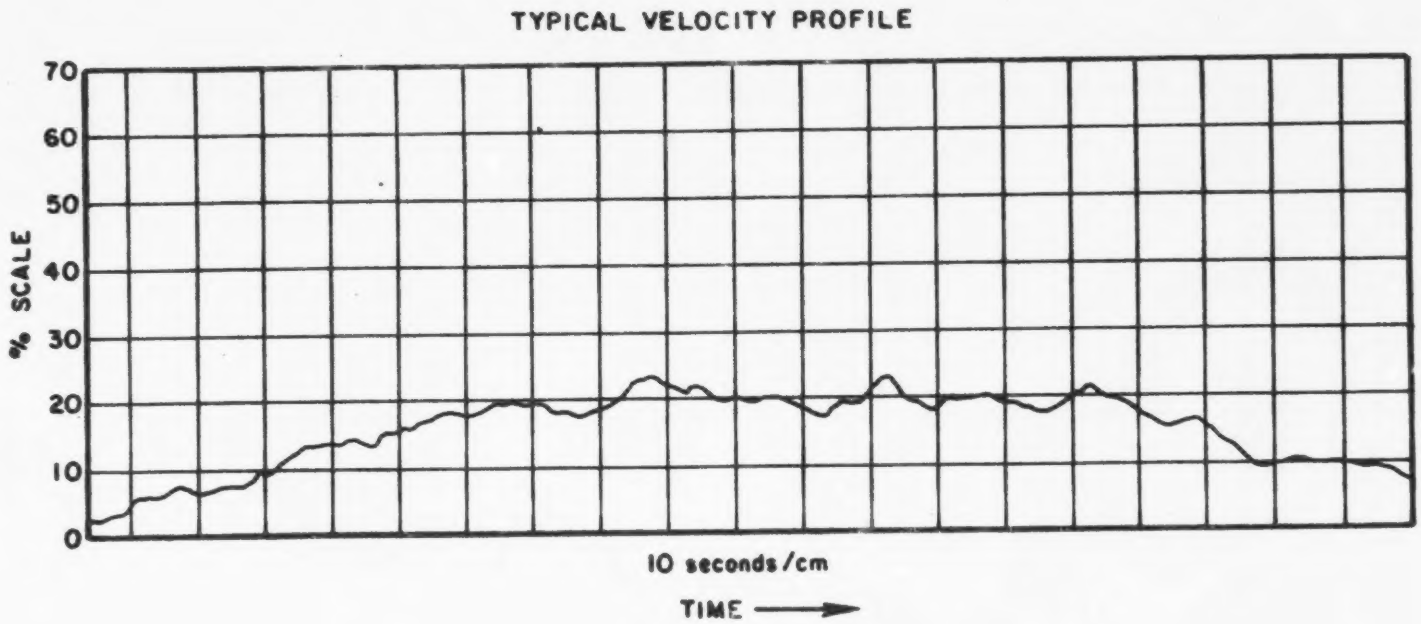


Figure 4. Typical velocity profile, DOFASCO No. 1 Quench Tower.

for the clean water testing and flushing liquor for the semi-dirty water testing. Sampling locations are shown in Figure 5. These sampling sites were selected to obtain samples which would trace the path of water pollutants through the quenching process. Comparing the numbers obtained at these different points provides an indication of pollutants lost from the water through emissions from the quench tower, or conversely, pollutants gained from contact with the hot coke during quenching.

Water samples were collected as a composite of grab samples taken during each quench making up the multi-quench tests. During each quench, a grab sample was taken at all three (quench, makeup and return) sampling locations. These grab samples were composited over an entire test period and treated as one composite sample for each location. A total volume of approximately 5 gallons per location was collected during each test period.

Upon completion of a test, the composite water samples were returned to the field trailer and mixed thoroughly before sample recovery and partial on-site analysis. Each composite was split into 8 aliquots for further analysis.

For all tests except the clean organic and dirty organic tests, sample containers were filled for the analyses of the following parameters: ammonia, chloride, cyanide, phenol, solids, sulfate, sulfide and an additional container was filled to serve as an extra sample.

SOURCE SIGNATURE SAMPLING

A dual cyclone particulate sampler, consisting of two cyclones in series and a back-up thimble filter, was developed by Southern Research Institute for particle size measurement in industrial process streams. Three particle size fractions are determined; greater than 15 microns, 2.5 to 15 microns, and less than 2.5 microns, when operated at a nominal flow rate of 0.8 cfm at 300°F. The sampler was run without interruption between quenches for sample periods ranging from approximately 4 to 10 hours.

The decision to run the dual cyclone sampler continuously was based on the desire to interrupt flow, which required moving the sampler, as little as possible in order to not disturb collected sample. It can be safely assumed that very little sample was collected during the period between quenches.

ORGANIC SAMPLING AND ANALYSIS

Organic samples of quench emissions at the inlet and outlet of the baffles were collected by placing an adsorbent trap in line between the filter and the impinger unit of the EPA Method 5 train.

The tests were run in one sampling port (the same for inlet and outlet) at approximately 0.75 CFM throughout the entire quenching process. Otherwise the same operating procedures discussed in the section on total particulate were adhered to. One test (inlet-outlet) was conducted for clean and one for dirty water quenching.

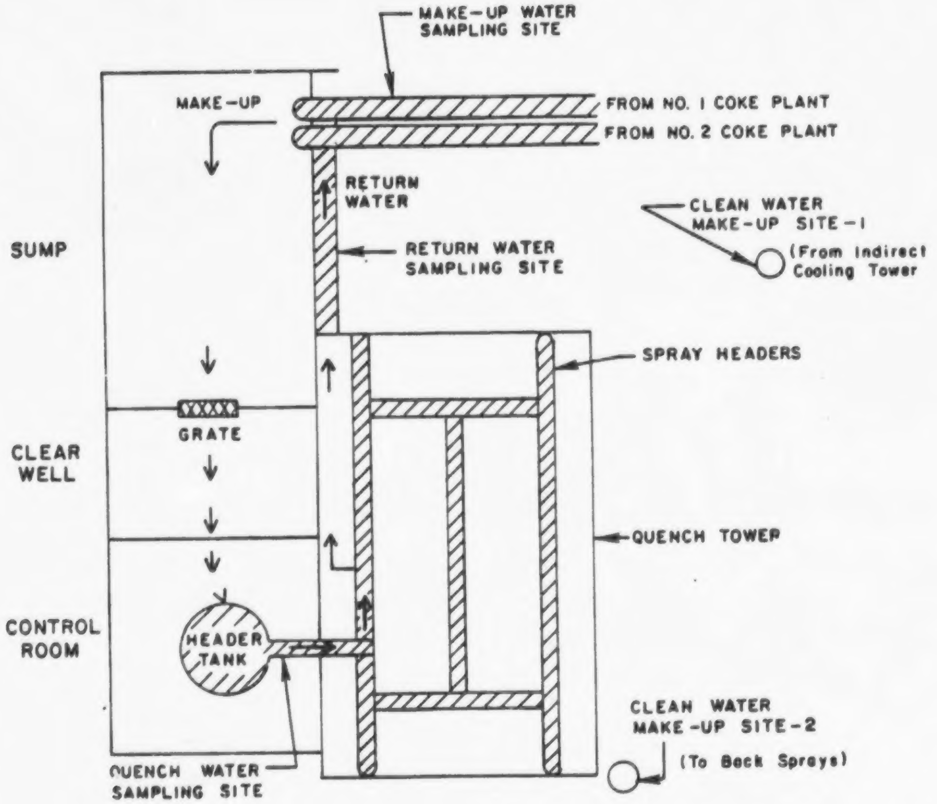

MAKE-UP WATER SAMPLING SITE
MAKE-UP
FROM NO. 1 COKE PLANT
FROM NO. 2 COKE PLANT
RETURN WATER
CLEAN WATER MAKE-UP SITE-1
(From Indirect Cooling Tower
SUMP
RETURN WATER SAMPLING SITE
SPRAY HEADERS
GRATE
CLEAR WELL
QUENCH TOWER
CONTROL ROOM
HEADER TANK
CLEAN WATER MAKE-UP SITE-2
(To Back Sprays)
QUENCH WATER SAMPLING SITE

Figure 5. Diagram of water flow and sampling locations.

Samples of quench, return, and makeup water were collected in the same manner as described earlier.

CONDENSABLE EMISSIONS

Measurement of condensable emissions were conducted by Southern Research Institute (SoRI). The IP condensable measurements were performed using the EPA Stack Dilution Sampling System (SDSS) which was operated according to IP protocol. Consult the operating manual (SoRI-EAS-80-806) for further details on the operation and sample recovery procedures.

GAS ANALYSIS: GC, ORSAT

Stack gas samples from DOFASCO's coke plant quench tower were analyzed for carbon dioxide, oxygen, and carbon monoxide using an Orsat gas analyzer, and for hydrocarbon content (C_1-C_6) using a Carle GC 9700 FID gas chromatograph.

Grab samples were taken randomly from quenches during clean, semi-dirty, and dirty water testing using a Tedlar bag and squeeze bulb. Samples were taken at the inlet of the baffle array during the clean water quench, and at the outlet during the semi-dirty and dirty water quenches. The results of orast analysis showed that the quench tower stack gas had essentially the same carbon dioxide, oxygen and carbon monixide content as ambient air.

Grab samples for gas chromatograph in analysis were taken during clean and dirty water quenches only. Prior to each GC analysis of the stack gas sample, standard C_1-C_6 was run to obtain a set of standard peaks from which the hydrocarbon content of the sample was calculated by proportion.

PROCESS OBSERVATIONS

The coke quench tower testing-program team included an environmental engineer experienced with coke plant operations. The process observer directed the testing via two way communication and documented all process and test conditions.

TEST RESULTS

The field sampling program was conducted during the last week of September and first three weeks of October. The program objectives were met by completion of five total particulate runs (simultaneous inlet-outlet) during clean water (500 mg/l TDS) quenching, three during semi-dirty (2270 mg/l TDS), and four during dirty water (8850 mg/l TDS) quenching. Five impactor runs (inlet-outlet simultaneous) during clean and four during dirty water quenching. Two dual cyclone sampler runs were performed for clean and dirty water quenching. One Modified Method 5 organic run was conducted for clean and dirty water usage. Water samples were taken during each quench tested. Process conditions were carefully monitored to insure that test runs were representative of the normal quenching practices at DOFASCO.

Water and organic samples were sent to Battelle Laboratory, Columbus, Ohio; Ontario Research, Mississauga, Ontario and the remaining samples driven back to the GCA/Technology Division laboratory for analysis.

TOTAL PARTICULATE RESULTS

The total particulate results from simultaneous above and below the baffles (outlet-inlet) testing are summarized in Table 1.

PARTICLE SIZE DISTRIBUTION RESULTS

The particle size distribution data from the individual test runs conducted simultaneously above and below the baffles during both clean and dirty water usage have been combined and compared by the Particulate Data Reduction System (PADRE), developed by RTI for EPA. The results are summarized in Figures 6 and 7.

WATER SAMPLING RESULTS

The results from the analysis of quench return and makeup waters are shown in Table 2.

DUAL CYCLONE SIGNATURE SAMPLING RESULTS

Only one dual cyclone unit was available at the time testing was conducted, therefore no simultaneous sampling was performed above and below the baffles. An inlet and outlet run were conducted for clean and dirty water usage. From the results obtained, it would seem that, only the results from the clean water outlet test compare to those found during the corresponding particulate tests. No correlation or further work has been conducted using these data.

DISCUSSION OF RESULTS

The linear relationship between air emissions and water quality, as measured by the TDS concentration into the quench water exists for both inlet to the baffles (uncontrolled emissions) and outlet (controlled emissions) results. This is the same conclusion as was reached from studies of pre-DOFASCO-'81 tests.

The emission rates at both the inlet and outlet of the baffles increase as the TDS level in the quench water increases. Linear regression analysis of the emission results compared against the TDS concentrations are shown in Figures 8 and 9. The slope of the line in Figure 9 (controlled) is very close to a line that can be extrapolated from the Gary #3 tower data obtained in 1979 by TRC.

The emission rates obtained prior to the baffles depicts emissions from an uncontrolled tower and can be utilized as an emissions factor for an unbaffled tower. However, other variables such as spray method, exit velocity, etc. must be considered before arbitrarily using these values.

TABLE 1. QUENCH TOWER EMISSION RATE SUMMARY - lb/ton COAL CHARGED, DOFASCO QUENCH TOWER NO. 1

Test type	Cyclone[a]	Probe	Filter	Total front half	Total back half	Total train	Quench mg/l TDS
Clean Inlet	0.83	0.19	0.11	1.13	0.12	1.25	510
Outlet	0.25	0.03	0.04	0.32	0.17	0.49	
Semi-dirty--Outlet	0.42	0.02	0.04	0.48	0.40	0.88	2,270
Dirty Inlet	3.88	0.33	1.03	5.24	0.56	5.80	8,850
Outlet	0.66	0.42	0.31	1.39	0.77	2.16	

[a] 3 μm D_{50} cut size.

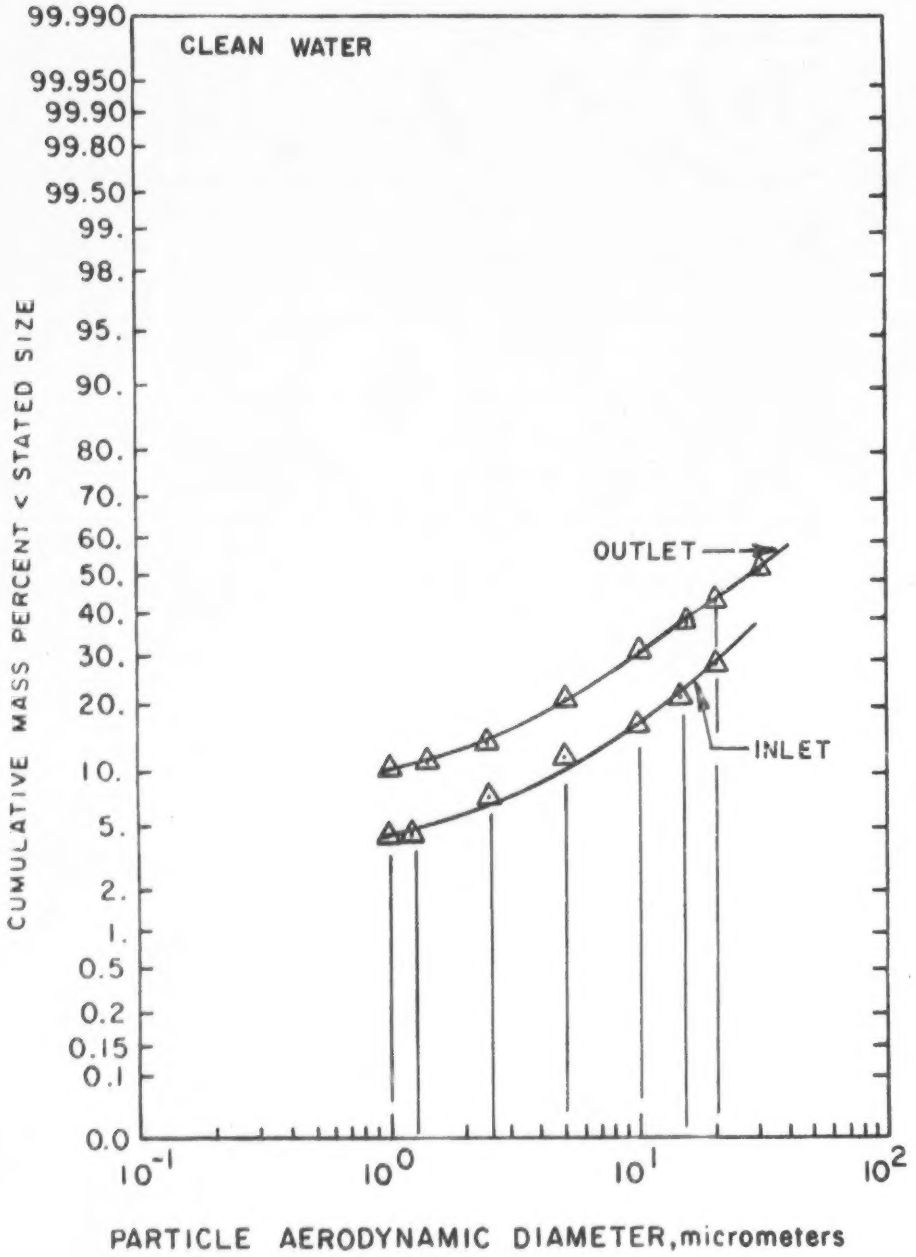


Figure 6. Average particle size distribution results for inlet and outlet tests performed during clean water usage, DOFASCO No. 1 Quench Tower.

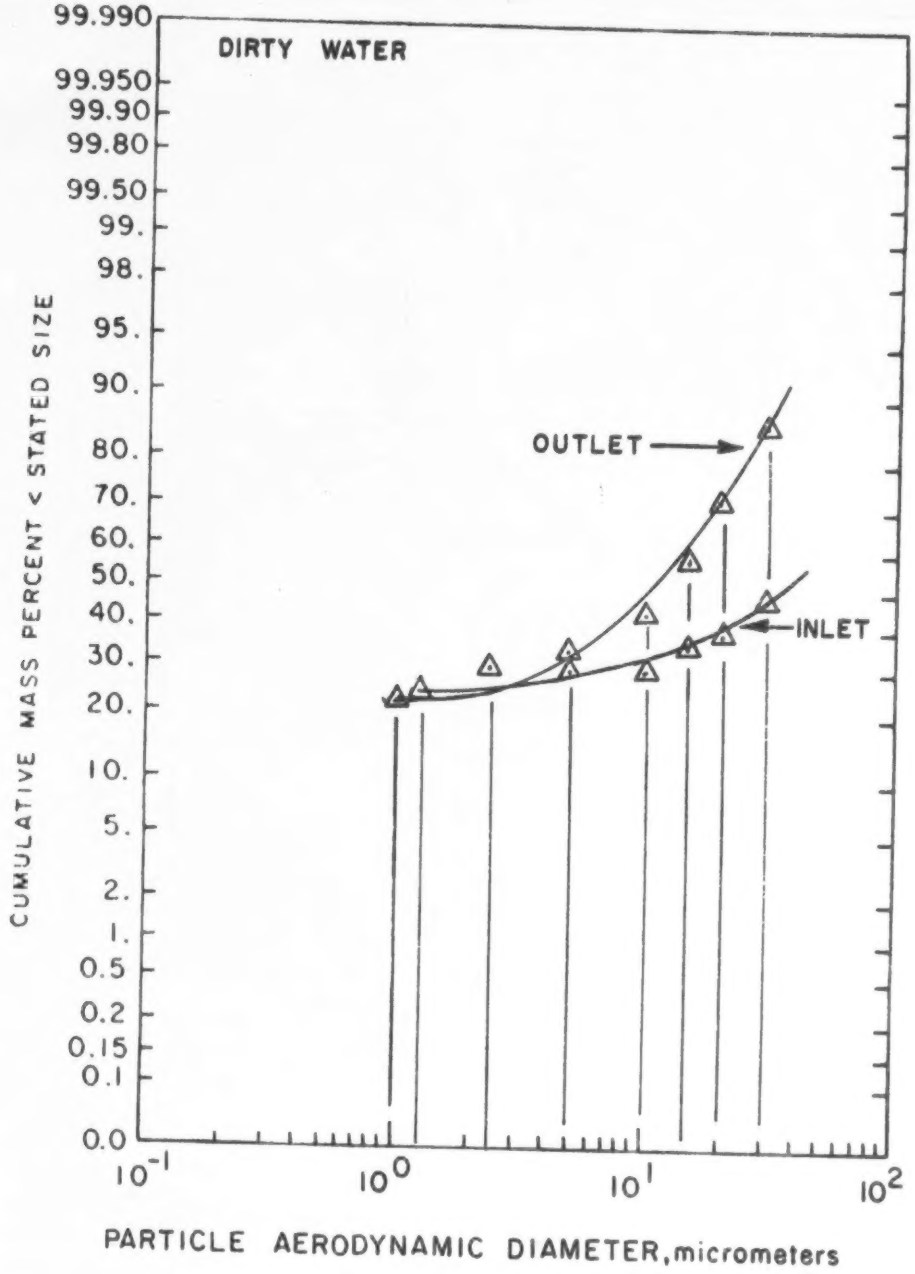


Figure 7. Average particle size distribution for inlet and outlet tests performed during dirty water usage, DOFASCO No. 1 Quench Tower.

TABLE 2. SUMMARY, DOFASCO QUENCH TOWER NO. 1

Parameter	Clean water			Semi-dirty water			Dirty water		
	Quench	Makeup	Return	Quench	Makeup	Return	Quench	Makeup	Return
Ammonia mg/l	3.4	0.99	2.24	527	3,733	517	2,300	2,928	2,416
Chloride mg/l	138	70	145	1,680	5,437	960	5,955	5,043	6,555
Conductivity mhos/cm	804	575	859	5,667	24,667	6,050	23,500	21,400	25,400
Cyanide, µg/ml	0.33	0.31	0.34	0.66	1.58	1.0			
Residual, mg/l							0.6	4.3	0.4
Amenable, mg/l							3.1	40.1	2.0
pH	8.5	7.5	8.4	7.8	8.55	7.4	8.1	9.0	7.7
Phenol, mg/l	0.336	0.0021	0.461	87.6	808	75.1	284	662	250
Solids, mg/l									
Dissolved	510	337	560	2,270	9,550	2,520	8,858	8,732	9,732
Suspended	57	4.8	273.3	114.2	409.4	284.6	154.5	383	414.5
Sulfate, µg/ml	126	61	138	169.5	266	191	348	68	407
Sulfide, mg/l	0.4	0.4	0.4	2.1	37.2	2.0	23.3	47.8	21.9
Temperature, °C	25.6	21.4	28.6	34.7	38.7	36.3	29	24.6	27.6

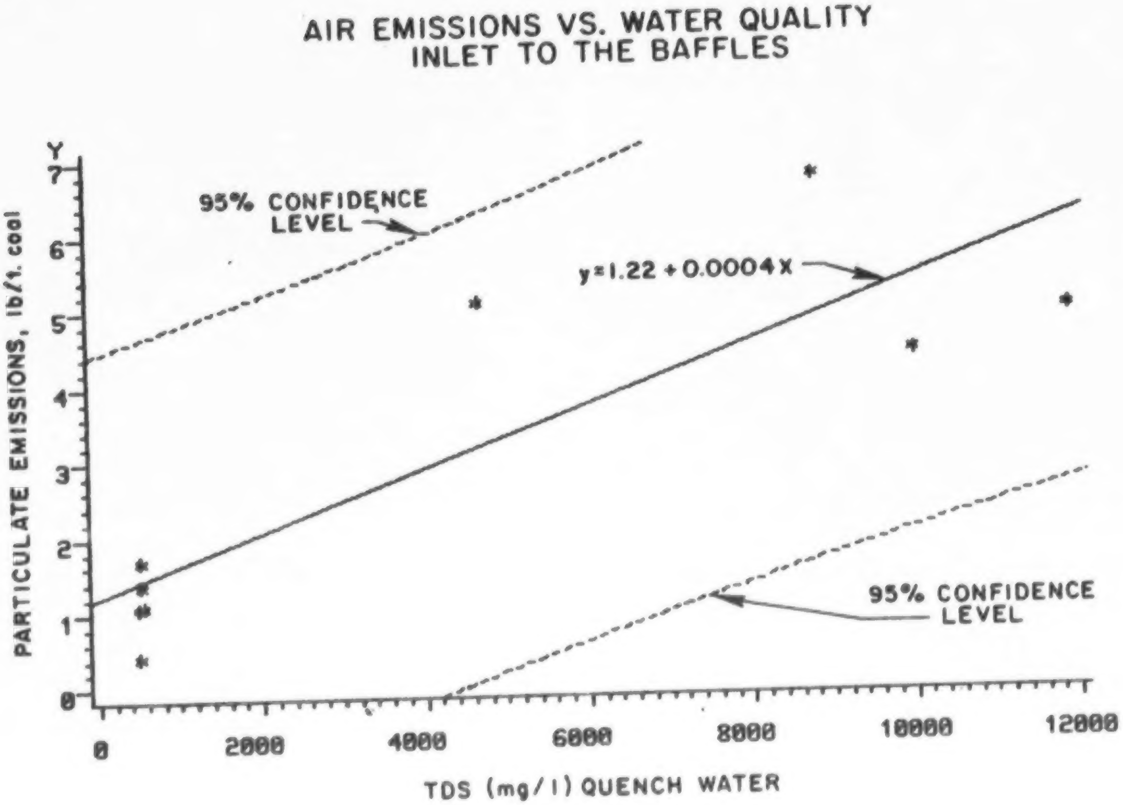


Figure 8. Air emissions vs. water quality, inlet of the baffles, DOFASCO No. 1 Quench Tower.

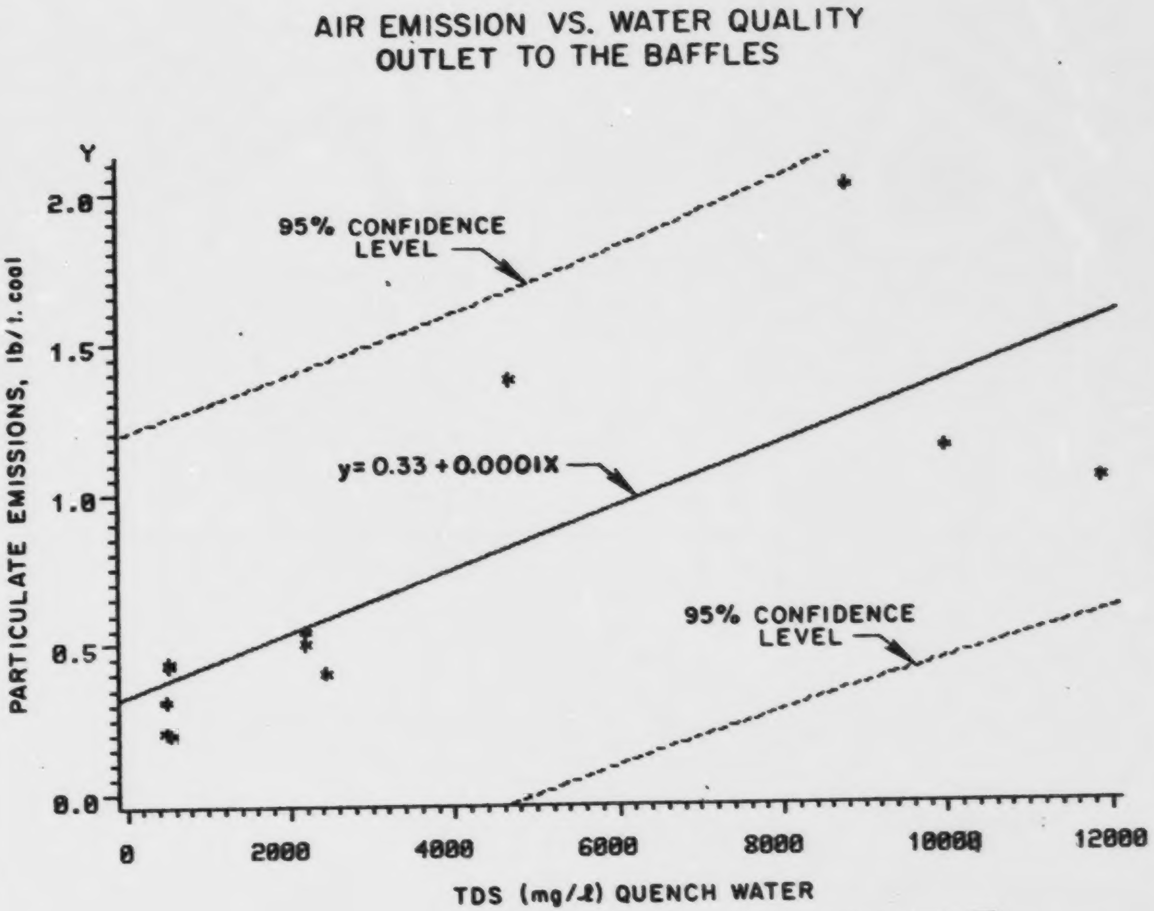


Figure 9. Air emission vs. water quality, outlet to the baffles, DOFASCO No. 1 Quench Tower.

Simultaneous sampling of the inlet and outlet of the baffle array has allowed the measurement of baffle efficiency for the first time. The computed value is 71% to 74% for clean and dirty water usage respectively. The implication of this result is that baffle efficiency is independent of the solids concentrations of the droplets formed during quenching.

With the efficiency data from these tests, a possible definition of effective baffles can now be made, (i.e. 70% or greater removal efficiency). Also, the inlet tests values can be utilized to estimate efficiency for any past or future sampling program where only the controlled side of the baffle system has been or will be tested.

All baffles do not behave identically; the DOFASCO-'81 tests indicate an emission of 0.48 lb/ton at 2270 mg/l; while the Gary #5 tests indicate 0.64 lb/ton at 1404 mg/l. The same measurement techniques were used and the towers are similar in design and exit velocities. The baffles are the only dominant variable.

Correlation between the DOFASCO'81 tests and the Gary #3 tests show emission rates are quite good for the tests run at 1588 mg/l at Gary #3 with an emission rate of 0.43 lb/ton and at 2270 mg/l at DOFASCO-'81 with a corresponding emission rate of 0.48 lb/ton. The tower and baffle designs are not similar but have produced emissions data comparable. Whether the Gary #3 emission rate can be extrapolated for water quality concentrations in the greater than 5000 mg/l TDS range is not yet known.

From the results obtained from this program, the Gary #3, Gary #5 DOFASCO '77, and Lorain studies, it can be safely stated that single row baffles placed a foot or more apart, do not achieve the removal efficiencies of the Munters T-271 or the Carl Still "A" frame baffles.

Analysis of the particle size data shows that during clean water quenching 50 percent of the particulate mater was less than 27 microns at the inlet to the baffles and at the same time 50 percent was less than 50 microns at the outlet. It would seem that large particles were able to travel through the baffles based on these data. Particulate buildup on the baffles spray cleaning system and visual observation during the first minute of quenching show this to occur. One possibility may be that these particles have not been wetted prior to their contact with the baffles and therefore are not affected. This possibly was addressed by the Munters Company in their original proposal to DOFASCO. This may also be a factor in the Gary # 3 and 5 tower study conducted by TRC for U.S. Steel at Gary. During dirty water usage at DOFASCO 50 percent of the particulate matter was less than 35 microns at the inlet to the baffles and at the outlet 50 percent was less than 15 microns.

The results of the dual cyclone tests are not considered to be accurate due to the inability to hold the sample temperature constant and prevent the condensation of moisture. The lack of dual cyclone calibration data over a range of flowrates and temperatures also contributes to the low reliability of the data.

Analysis of the water sample data reveals the following:

- when both clean and dirty water was used for make-up purposes, there was no indication of a concentrating effect between the TDS levels in the make-up water and the quench water, however, the tests were not conducted over more than a 5 day period.
- species found in the water supply system of the quench tower for both clean and dirty water usage was comparable to other facilities that have been previously tested.

The data from the organic sampling tests show no apparent correlation between the air emission results and the results from the water samples taken during these tests. Due to contamination of some of these samples, further analysis is not being considered at this time.

The condensible emissions tests conducted and reported by Southern Research Institute show that the total concentration of mass runs from the in-stack IP unit ranged from 55 to 72 percent of the total concentration obtained in parallel SDSS runs. This was the first time that this unit was used to measure quench tower condensible emissions and as such, no comparisive data is available.

BEGIN FIRST LINE OF TEXT HERE
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD; BEGIN SECTIONS HERE

SESSION 2: SOLID WASTE POLLUTION ABATEMENT

Chairmen: Penelope Hansen
Hazardous Industrial Waste Division
U.S. Environmental Protection Agency
Washington, DC

David G. Boltz
Solid Waste Control
Bethlehem Steel Corporation
Bethlehem, PA

9-1/8"
BEGIN LAST LINE OF TEXT
3/8"
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS

PAGE NUMBER
EPA Form 2350-4 (4-80)
(PREVIOUSLY CIN. EPA FORM 257)
TYPING GUIDE SHEET

DISCLAIMER

The work described in this paper was not funded by the U.S. Environmental Protection Agency. The contents do not necessarily reflect the views of the Agency and no official endorsement should be inferred.

GROUNDWATER MONITORING STRATEGIES FOR STEEL INDUSTRY RESIDUE DISPOSAL OPERATIONS

by: Andrew P. Pajak and David W. Hupe
Michael Baker, Jr., Inc.
4301 Dutch Ridge Road
Beaver, PA 15009

ABSTRACT

Regulations issued by the U.S. Environmental Protection Agency and state regulatory agencies require that owners or operators of existing and new surface impoundment, landfill, or land treatment hazardous waste management facilities implement a groundwater monitoring program. Moreover, evolving non-hazardous waste regulations are including groundwater monitoring and protection requirements. RCRA hazardous waste regulations published on July 26, 1982 are significantly different than previously imposed regulations. This paper highlights the new regulatory approach and differences between the existing and new federal RCRA regulations, especially in the area of flexibility and variances. Design of an acceptable monitoring network and protocol are discussed. Problems experienced in monitoring network design and interpretation of resulting data are illustrated. Concise flowcharts of actions required by the regulations and an outline for designing a groundwater monitoring program are provided.

INTRODUCTION

Most owners or operators of hazardous waste treatment, storage, or disposal facilities with interim status have, as required by Resource Conservation and Recovery Act (RCRA) regulations promulgated on May 19, 1980, initiated groundwater monitoring programs. In fact, Baker Engineers has assisted numerous steel industry clients in designing and implementing these programs. However, on July 26, 1982, new interim final regulations (Subtitle C, Part 264, Subpart F) were published specifying a substantially revised groundwater monitoring and response program that must be applied at new and existing surface impoundments, landfills, waste piles, and land treatment facilities. Rather than utilize previous projects as case studies to describe groundwater monitoring approaches, this paper focuses on several key areas of the new regulations; especially, those areas that allow the regulated entity to use technical judgments in complying with the objectives of the regulations.

An overview of the groundwater monitoring requirements of the July 26, 1982 regulations is presented. Steps in designing and implementing a technically acceptable program then are outlined. Problems experienced by

Baker Engineers on previous projects are identified. The remainder of this paper highlights areas of the regulations allowing flexibility (but requiring a sound technical basis to gain variances) and briefly addresses a risk analysis approach to formulating the technical basis.

OVERVIEW - GROUNDWATER MONITORING AND RESPONSE PROGRAM

In the interim final RCRA regulations of July 26, 1982, three types of groundwater monitoring programs are specified: detection monitoring, compliance monitoring, and corrective action. The objectives are to:

1. detect leakage from the regulated unit (any impoundment, landfill, pile or land treatment waste management unit that receives hazardous waste after January 26, 1983)

2. determine if contaminant concentrations in the groundwater exceed levels that protect human health and the environment, and

3. undertake and measure the effectiveness of corrective actions if these concentrations have been exceeded.

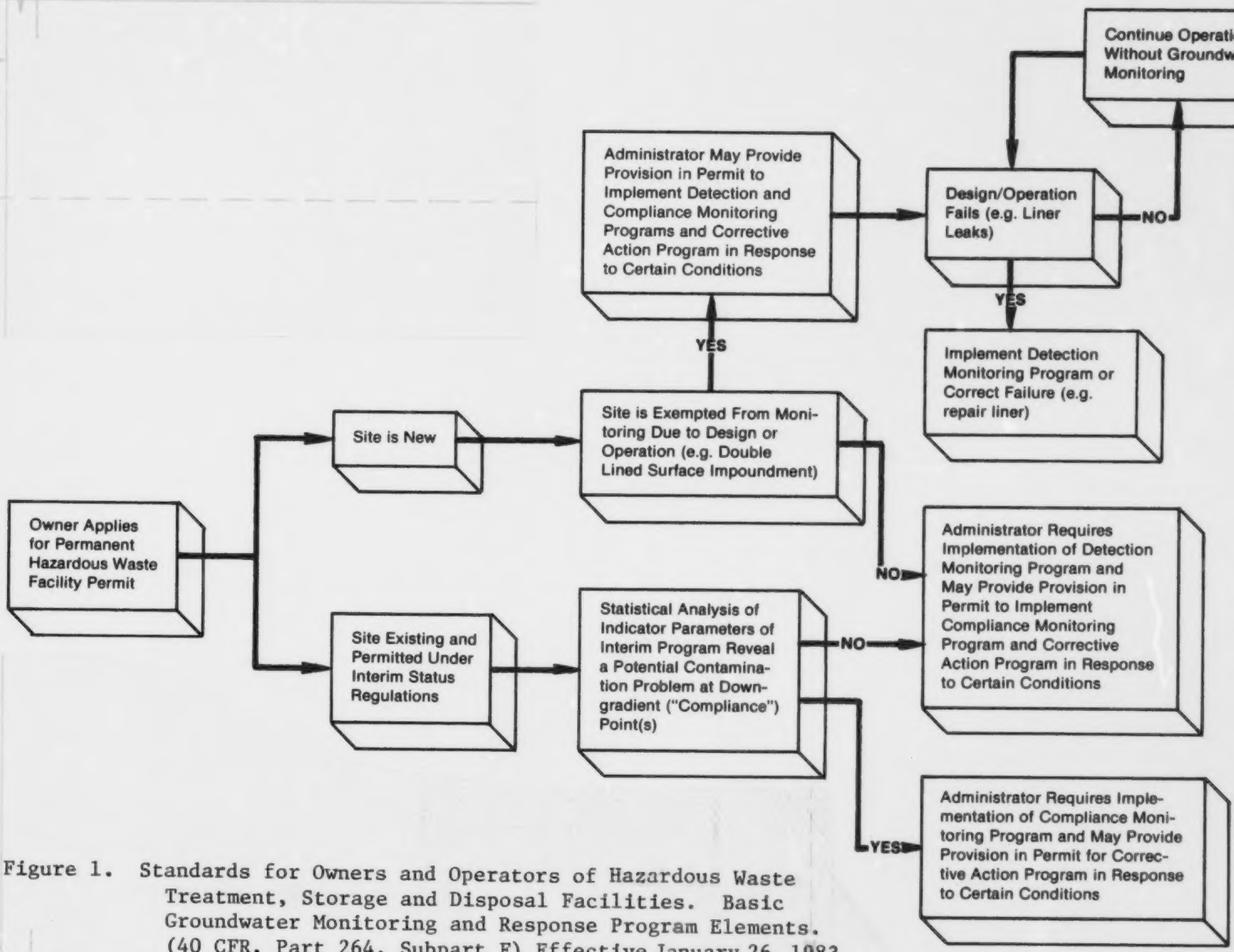
The programs must be conducted throughout the active life of the unit as well as a post-closure care period. They dictate increased response to groundwater contamination as evidence of contamination increases. Therefore, the programs may be implemented sequentially, or it may be necessary to shift between the compliance and corrective programs when hazardous constituent levels in the groundwater fluctuate above and below constituent limits, or it may never be necessary to go beyond detection monitoring. However, only one program can be in operation at a time. Figure 1 presents an overview of the groundwater monitoring and protection approach. Figures 2, 3, and 4 illustrate more detailed flowcharts of the actions required in each of the three programs.

GROUNDWATER MONITORING PROGRAM DESIGN

As might be expected, the level of effort required to design and implement the groundwater monitoring program is site specific. Availability of background data, complexity of site history and uses, variability of subsurface conditions, site accessibility, proximity to other potential sources of contaminants and potential water users, as well as other factors play significant controlling roles in the final effort required. A detailed explanation of a recommended sequence for design of a monitoring program to comply with the new hazardous waste regulations cannot be provided within the extent of this paper. Therefore, an outline is provided in Table 1. It can serve as a reference planning tool during formulation of early monitoring (detection type) programs. This outline recounts most of the actual steps followed during a recent investigation by Baker Engineers for a major steel industry client.

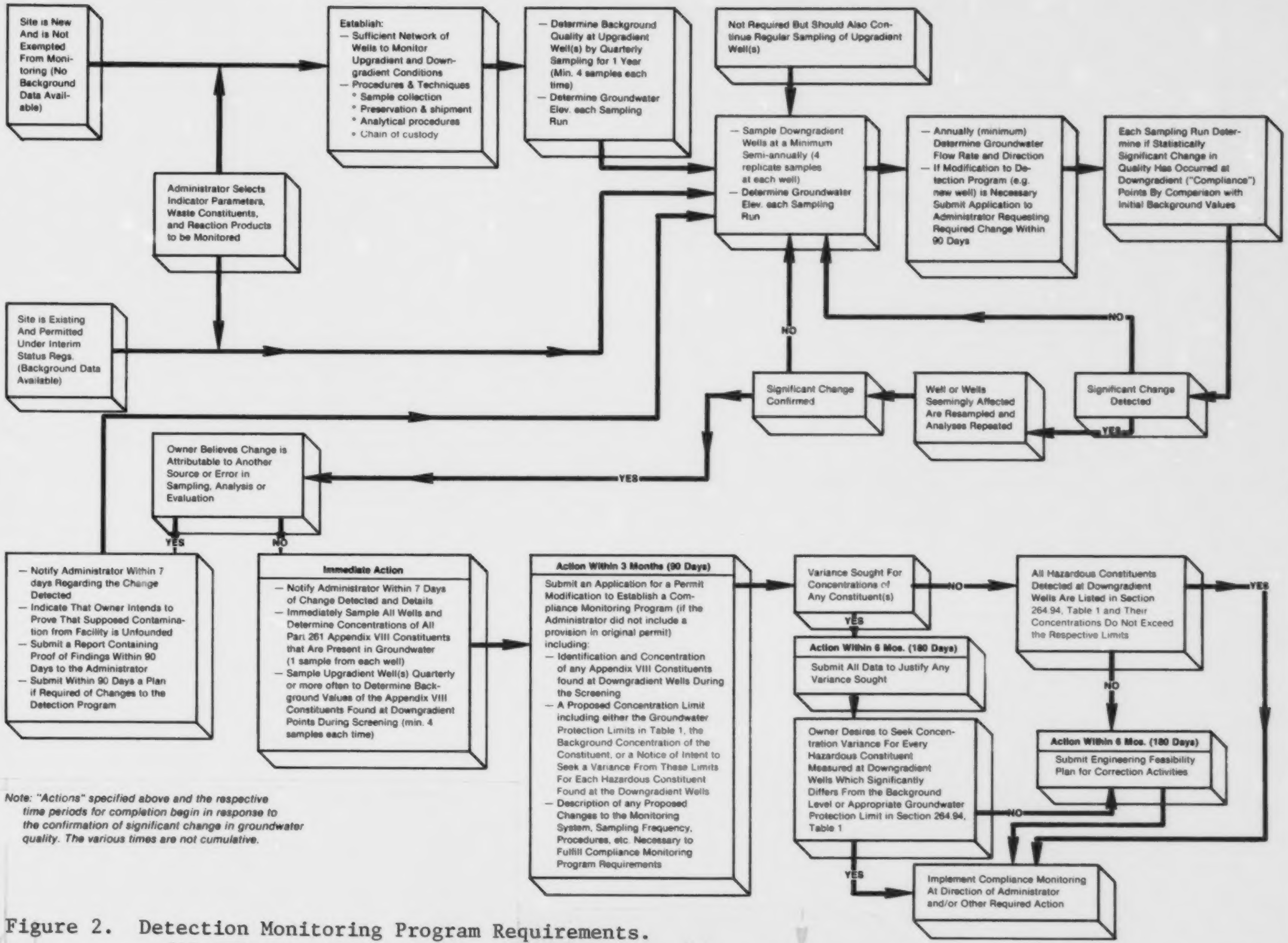
Several problems have been encountered during the monitoring projects which are worth noting as they may relate to steel industry monitoring

EPA Form 2350-4 (4-80)
(PREVIOUSLY CIN: EPA FORM 287)
TYPING GUIDE SHEET



Owner Applies for Permanent Hazardous Waste Facility Permit
Site is New
Site Existing and Permitted Under Interim Status Regulations
Site is Exempted From Monitoring Due to Design or Operation (e.g. Double Lined Surface Impoundment)
Statistical Analysis of Indicator Parameters of Interim Program Reveal a Potential Contamination Problem at Downgradient ("Compliance") Point(s)
YES
Administrator May Provide Provision in Permit to Implement Detection and Compliance Monitoring Programs and Corrective Action Program in Response to Certain Conditions
Design/Operation Fails (e.g. Liner Leaks)
NO
Continue Operation Without Groundwater Monitoring
YES
Implement Detection Monitoring Program or Correct Failure (e.g. repair liner)
NO
NO
Administrator Requires Implementation of Detection Monitoring Program and May Provide Provision in Permit to Implement Compliance Monitoring Program and Corrective Action Program in Response to Certain Conditions
YES
Administrator Requires Implementation of Compliance Monitoring Program and May Provide Provision in Permit for Corrective Action Program in Response to Certain Conditions

Figure 1. Standards for Owners and Operators of Hazardous Waste Treatment, Storage and Disposal Facilities. Basic Groundwater Monitoring and Response Program Elements. (40 CFR, Part 264, Subpart F) Effective January 26, 1983.


Site is New And is Not Exempted From Monitoring (No Background Data Available)
Establish:
— Sufficient Network of Wells to Monitor Upgradient and Downgradient Conditions
— Procedures & Techniques
° Sample collection
° Preservation & shipment
° Analytical procedures
° Chain of custody
— Determine Background Quality at Upgradient Well(s) by Quarterly Sampling for 1 Year (Min. 4 samples each time)
— Determine Groundwater Elev. each Sampling Run
Not Required But Should Also Continue Regular Sampling of Upgradient Well(s)
Administrator Selects Indicator Parameters, Waste Constituents, and Reaction Products to be Monitored
— Sample Downgradient Wells at a Minimum Semi-annually (4 replicate samples at each well)
— Determine Groundwater Elev. each Sampling Run
— Annually (minimum) Determine Groundwater Flow Rate and Direction
— If Modification to Detection Program (e.g. new well) is Necessary Submit Application to Administrator Requesting Required Change Within 90 Days
Each Sampling Run Determine if Statistically Significant Change in Quality Has Occurred at Downgradient ("Compliance") Points By Comparison with Initial Background Values
Site is Existing And Permitted Under Interim Status Regs. (Background Data Available)
NO
NO
Significant Change Confirmed
Well or Wells Seemingly Affected Are Resampled and Analyses Repeated
Significant Change Detected
YES
YES
Owner Believes Change is Attributable to Another Source or Error in Sampling, Analysis or Evaluation
YES
NO
— Notify Administrator Within 7 days Regarding the Change Detected
— Indicate That Owner Intends to Prove That Supposed Contamination from Facility is Unfounded
— Submit a Report Containing Proof of Findings Within 90 Days to the Administrator
— Submit Within 90 Days a Plan if Required of Changes to the Detection Program
Immediate Action
— Notify Administrator Within 7 Days of Change Detected and Details
— Immediately Sample All Wells and Determine Concentrations of All Part 261 Appendix VIII Constituents that Are Present in Groundwater (1 sample from each well)
— Sample Upgradient Well(s) Quarterly or more often to Determine Background Values of the Appendix VIII Constituents Found at Downgradient Points During Screening (min. 4 samples each time)
Action Within 3 Months (90 Days)
Submit an Application for a Permit Modification to Establish a Compliance Monitoring Program (if the Administrator did not include a provision in original permit) including:
— Identification and Concentration of any Appendix VIII Constituents found at Downgradient Wells During the Screening
— A Proposed Concentration Limit including either the Groundwater Protection Limits in Table 1, the Background Concentration of the Constituent, or a Notice of Intent to Seek a Variance From These Limits For Each Hazardous Constituent Found at the Downgradient Wells
— Description of any Proposed Changes to the Monitoring System, Sampling Frequency, Procedures, etc. Necessary to Fulfill Compliance Monitoring Program Requirements
Variance Sought For Concentrations of Any Constituent(s)
NO
YES
Action Within 6 Mos. (180 Days)
Submit All Data to Justify Any Variance Sought
Owner Desires to Seek Concentration Variance For Every Hazardous Constituent Measured at Downgradient Wells Which Significantly Differs From the Background Level or Appropriate Groundwater Protection Limit in Section 264.94, Table 1
NO
YES
All Hazardous Constituents Detected at Downgradient Wells Are Listed in Section 264.94, Table 1 and Their Concentrations Do Not Exceed the Respective Limits
YES
NO
Action Within 6 Mos. (180 Days)
Submit Engineering Feasibility Plan for Correction Activities
Implement Compliance Monitoring At Direction of Administrator and/or Other Required Action

Note: "Actions" specified above and the respective time periods for completion begin in response to the confirmation of significant change in groundwater quality. The various times are not cumulative.

Figure 2. Detection Monitoring Program Requirements. (40 CFR, Part 264, Subpart F, Section 264.98)

BEGIN FIRST LINE OF TEXT HERE
DROPPED HEAD; BEGIN SECTIONS HERE
CENTER OF PAGE
TOP OF IMAGE AREA

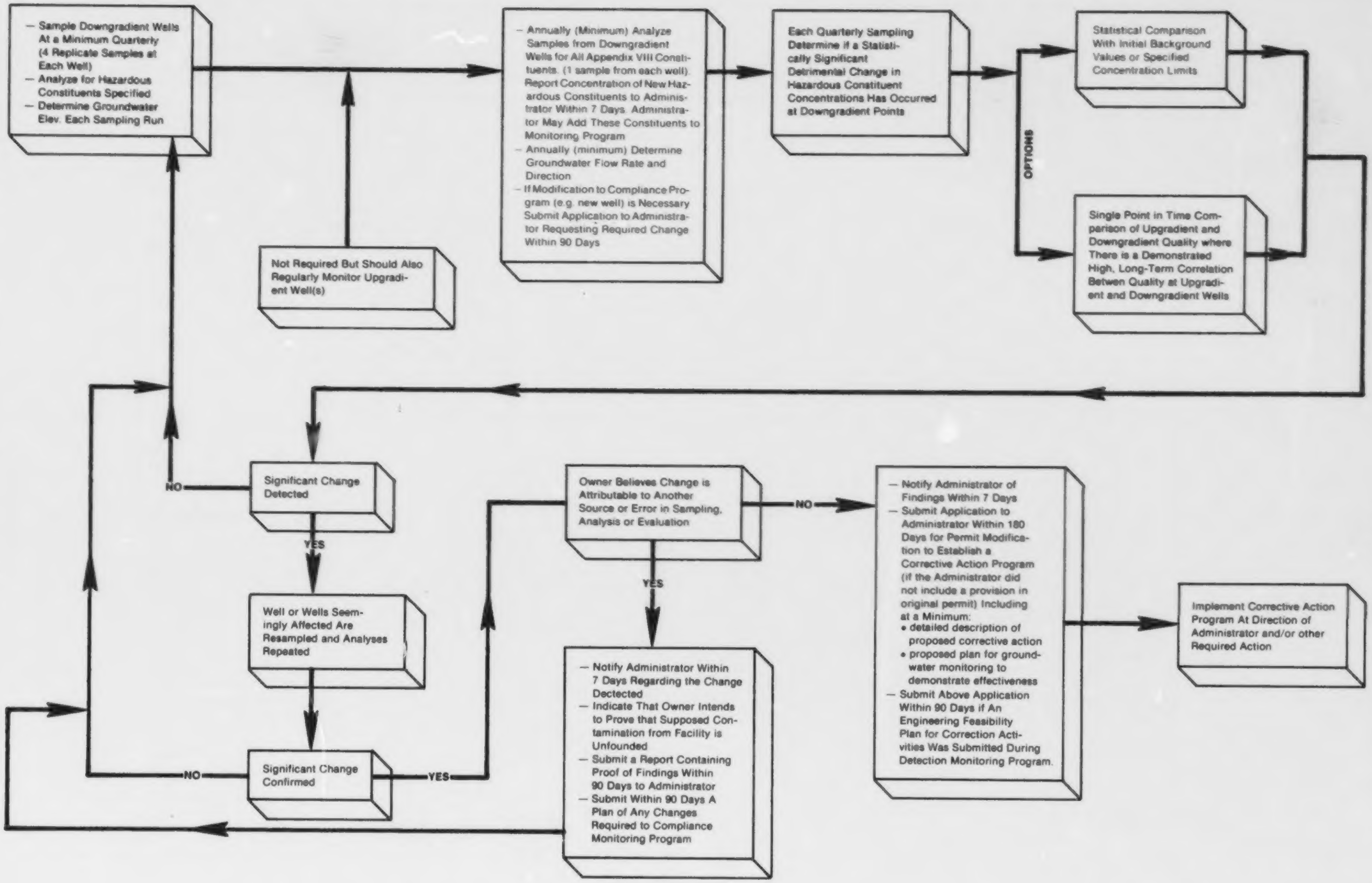

– Sample Downgradient Wells At a Minimum Quarterly (4 Replicate Samples at Each Well)
– Analyze for Hazardous Constituents Specified
– Determine Groundwater Elev. Each Sampling Run
Not Required But Should Also Regularly Monitor Upgradient Well(s)
– Annually (Minimum) Analyze Samples from Downgradient Wells for All Appendix VIII Constituents. (1 sample from each well). Report Concentration of New Hazardous Constituents to Administrator Within 7 Days. Administrator May Add These Constituents to Monitoring Program
– Annually (minimum) Determine Groundwater Flow Rate and Direction
– If Modification to Compliance Program (e.g. new well) is Necessary Submit Application to Administrator Requesting Required Change Within 90 Days
Each Quarterly Sampling Determine if a Statistically Significant Detrimental Change in Hazardous Constituent Concentrations Has Occurred at Downgradient Points
OPTIONS
Statistical Comparison With Initial Background Values or Specified Concentration Limits
Single Point in Time Comparison of Upgradient and Downgradient Quality where There is a Demonstrated High, Long-Term Correlation Betwen Quality at Upgradient and Downgradient Wells
Significant Change Detected
NO
YES
Well or Wells Seemingly Affected Are Resampled and Analyses Repeated
Significant Change Confirmed
NO
YES
Owner Believes Change is Attributable to Another Source or Error in Sampling, Analysis or Evaluation
YES
NO
– Notify Administrator Within 7 Days Regarding the Change Dectected
– Indicate That Owner Intends to Prove that Supposed Contamination from Facility is Unfounded
– Submit a Report Containing Proof of Findings Within 90 Days to Administrator
– Submit Within 90 Days A Plan of Any Changes Required to Compliance Monitoring Program
– Notify Administrator of Findings Within 7 Days
– Submit Application to Administrator Within 180 Days for Permit Modification to Establish a Corrective Action Program (if the Administrator did not include a provision in original permit) Including at a Minimum:
• detailed description of proposed corrective action
• proposed plan for groundwater monitoring to demonstrate effectiveness
– Submit Above Application Within 90 Days if An Engineering Feasibility Plan for Correction Activities Was Submitted During Detection Monitoring Program.
Implement Corrective Action Program At Direction of Administrator and/or other Required Action

Figure 3. Compliance Monitoring Program Requirements. (40 CFR, Part 264, Subpart F, Section 264.99)

BEGIN LAST LINE OF TEXT
3/8"
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
PAGE NUMBER
EPA Form 2350-4 (4-80)
(PREVIOUSLY CIN. EPA FORM 287)
TYPING GUIDE SHEET

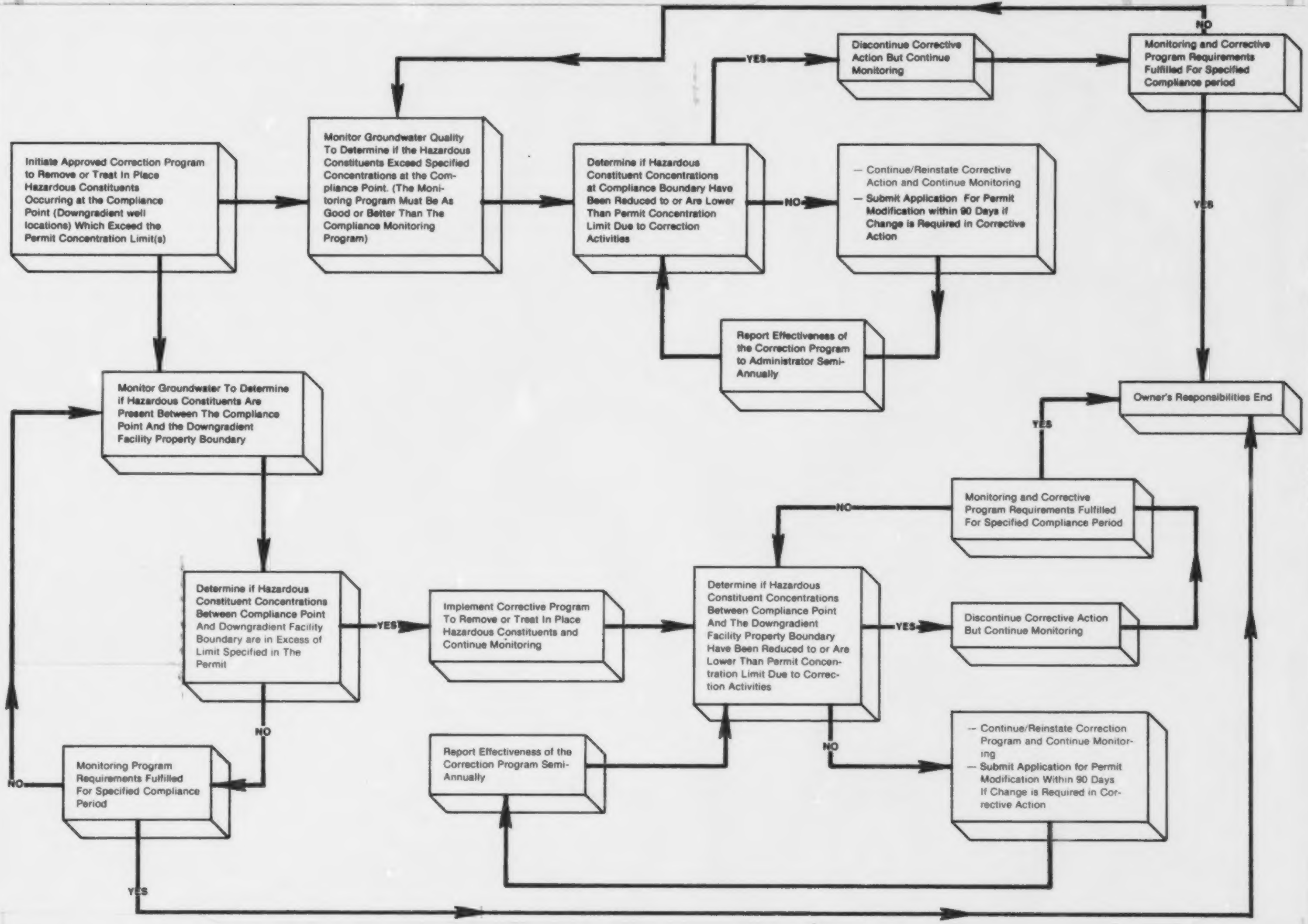

Initiate Approved Correction Program to Remove or Treat In Place Hazardous Constituents Occurring at the Compliance Point (Downgradient well locations) Which Exceed the Permit Concentration Limit(s)
Monitor Groundwater Quality To Determine if the Hazardous Constituents Exceed Specified Concentrations at the Compliance Point. (The Monitoring Program Must Be As Good or Better Than The Compliance Monitoring Program)
Determine if Hazardous Constituent Concentrations at Compliance Boundary Have Been Reduced to or Are Lower Than Permit Concentration Limit Due to Correction Activities
YES
Discontinue Corrective Action But Continue Monitoring
NO
— Continue/Reinstate Corrective Action and Continue Monitoring
— Submit Application For Permit Modification within 90 Days if Change is Required in Corrective Action
Report Effectiveness of the Correction Program to Administrator Semi-Annually
Monitoring and Corrective Program Requirements Fulfilled For Specified Compliance period
NO
YES
Owner's Responsibilities End
Monitor Groundwater To Determine if Hazardous Constituents Are Present Between The Compliance Point And the Downgradient Facility Property Boundary
Determine if Hazardous Constituent Concentrations Between Compliance Point And Downgradient Facility Boundary are in Excess of Limit Specified in The Permit
YES
Implement Corrective Program To Remove or Treat In Place Hazardous Constituents and Continue Monitoring
NO
Monitoring Program Requirements Fulfilled For Specified Compliance Period
NO
YES
Determine if Hazardous Constituent Concentrations Between Compliance Point And The Downgradient Facility Property Boundary Have Been Reduced to or Are Lower Than Permit Concentration Limit Due to Correction Activities
YES
Discontinue Corrective Action But Continue Monitoring
NO
— Continue/Reinstate Correction Program and Continue Monitoring
— Submit Application for Permit Modification Within 90 Days If Change is Required in Corrective Action
Report Effectiveness of the Correction Program Semi-Annually
Monitoring and Corrective Program Requirements Fulfilled For Specified Compliance Period
NO
YES

Figure 4. Corrective Action Program Requirements.
(40 CFR, Part 264, Subpart F, Section 264.100)

BEGIN FIRST LINE OF TEXT HERE
DROPPED HEAD. BEGIN SECTIONS HERE
CENTER OF PAGE
TOP OF IMAGE AREA
BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"
PAGE NUMBER
EPA Form 2350-4 (4-80)
(PREVIOUSLY CIN: EPA FORM 287)
TYPING GUIDE SHEET

TABLE 1. OUTLINE FOR GROUNDWATER MONITORING PROGRAM DESIGN

- I. Conduct Initial Background Investigations
  - A. Research published literature
    - 1. Regional geology, soils, and probable aquifers
    - 2. Regional groundwater quality and water well completion records
    - 3. Potential background sources of contamination
  - B. Obtain background data from site personnel/owner
    - 1. Local drilling logs/well logs
      - a. underlying natural liners or permeable zones
      - b. approximate depth to groundwater
      - c. groundwater quality
    - 2. Site history
      - a. historic uses
      - b. natural soils in-place or disturbed
      - c. other wastes previously disposed on or near site and still present or removed
    - 3. Base mapping and aerial photos
    - 4. Anticipated disposal area extent and configuration
    - 5. Waste characteristics (physical, chemical)
  - C. Field reconnaissance and mapping in immediate vicinity of disposal site
    - 1. Locate outcrops for geologic correlations
    - 2. Locate existing wells and springs as potential monitoring points
    - 3. Map pertinent site features and identify other potential contamination sources
    - 4. Identify possible monitoring well locations
- II. Develop Conceptual Monitoring Plan
  - A. Compile general geologic profile for site by correlating available site subsurface and outcrop information
  - B. Identify appropriate aquifer(s) to be monitored
  - C. Select preliminary monitoring well locations and appropriate depths (consider including significant springs or substituting them for wells)
  - D. Identify additional data needed
  - E. Review with site personnel/owner
- III. Conduct Subsurface Investigation(s) to Supplement Existing Data
  - A. Exploratory drilling
    - 1. Drill appropriate number of exploratory borings around existing site as deep or deeper than the uppermost aquifer and potentially interconnected underlying aquifers and minimum 10 feet into groundwater. For new site drill a few similar borings on-site
    - 2. Conduct pump tests or laboratory permeability tests on aquifer materials and determine permeability and porosity (required for annual evaluations of rate of groundwater flow)
    - 3. Case exploratory borings to maintain open holes

EPA Form 2350-4 (4-80)
(PREVIOUSLY CIN EPA FORM 237)
TYPING GUIDE SHEET

TABLE 1. (continued)

    4. Fully characterize site soils through laboratory classifications
  - B. Determine direction of groundwater movement
    1. Allow groundwater levels in exploratory borings to equalize
    2. Measure groundwater levels in all exploratory borings, existing wells, and determine surface elevation of all local lakes, etc.
    3. Contour data to define direction(s) of local groundwater movement
  - C. Geophysical surveying as possible supplement or substitute for drilling
- IV. Design Permanent Monitoring Plan
  - A. Design and install permanent monitoring system
    1. Revise preliminary geologic profile using supplementary subsurface data
    2. Revise conceptual well depths and locations as dictated by new profile and groundwater flow pattern
    3. Convert exploratory borings to permanent monitoring wells, install additional wells, and/or develop springs to adequately monitor background and downgradient conditions. Grout exploratory holes not used for monitoring.
  - B. Formulate sampling and analysis procedures
    1. Sampling stations (drilled monitoring wells, existing wells, springs, related surface water samples)
    2. Select parameters to be analyzed
       - a. general indicators of contamination
       - b. expected specific parameters related to waste type and potential reaction products
    3. Identify sampling frequency (at least semi-annually required)
    4. Well evacuation and sampling methods and equipment to assure representative samples are obtained
    5. Sample volumes, container types, and sample handling/preservation to assure sample integrity
    6. Field versus laboratory analyses
    7. Documentation procedures for field activities
    8. Sample custody control and documentation to establish a record of proper sample handling
    9. Analytical methods for desired detection level
    10. Quality control
    11. Resampling and possible sample splitting
  - C. Formulate data management procedures
    1. Computer storage of data and assist in calculating statistical difference from background using student T-test
    2. Graphical summaries for trend or single-point-in-time comparisons
    3. Reporting procedures and format
- V. Implement Monitoring Plan

situations. Foremost is the situation where the disposal site being monitored is situated on or near other waste disposal sites. In these circumstances, it may be nearly impossible to determine conclusively if the disposal site being monitored is the source of detected contaminants, especially if similar waste constituents are present in both areas. Much more work than usual may be necessary at such sites to adequately characterize background influences so that these contributions are not wrongly attributed to the disposal site.

A second significant problem relates to selection of monitoring well locations and long-term protection of the wells. Downgradient, detection type monitoring wells must be situated as close as possible to the waste management unit to provide early warning of groundwater contamination. Additionally, the path of probable downgradient flows from a relatively small waste unit usually is very limited in width. Similarly, proper location of upgradient wells may be very crucial in some instances to properly define upgradient or background quality, especially when affected by another localized source. As a result, suitable areas for location of both downgradient and upgradient wells to accomplish the necessary monitoring usually are very limited.

Repeatedly, owners of waste disposal sites fail to recognize the lack of freedom in monitoring well placement without significantly compromising the monitoring objectives. Owners and their plant personnel must dedicate the necessary locations for monitoring points and endeavor to protect these locations. Although monitoring wells routinely are protected at the ground surface using steel casing, wells have been lost in the past due to inadvertent damage by heavy equipment, burial, and inundation.

Another subject for concern is the overseeing (quality control) of continuing monitoring activities. The best designed monitoring program can be severely compromised if proper evacuation of wells before sampling, prevention of cross contamination of wells, proper sampling and preservation of samples, laboratory quality control, and consistency are not given proper attention. The ultimate monitoring results may be erroneous and confusing as well as indefensible if questioned by regulatory agencies.

AREAS OF FLEXIBILITY OR NEGOTIATION

Within each of the three monitoring programs there are several areas where the interim final regulations specify that actions must be taken, but leave the details to be resolved by the regulated entity and EPA Regional Administrator. Moreover, partial or entire exclusions from groundwater monitoring can be obtained for specific types of units (piles), designs (landfills and impoundments with double liners), operations (hazardous constituents of waste have been effectively treated), or site locations (hydrogeologic setting precluding potential for hazardous constituent migration to uppermost aquifer during active life and post-closure care period; or, possibly in rare circumstances, where the uppermost aquifer is severely contaminated and cannot be used provided that this aquifer is isolated from other aquifers or surface waters).

EPA Form 2350-4 (4-80)
(PREVIOUSLY CIN. EPA FORM 287)
TYPING GUIDE SHEET

In the detection and compliance monitoring programs, resolution of the following major issues are based upon situation-specific information:

- selection of the parameters to be monitored based upon types and quantities of wastes managed at the unit and waste constituent concentrations, leachate reactions with underlying soils, detection procedures and accuracies, and variability of background groundwater quality

- development of a monitoring network yielding representative samples; the number of monitoring wells at the compliance point are not specified and continued sampling of upgradient wells is not mandated although it will be necessary to effectively accomplish the program

- specification of groundwater protection standards comprised of a list of hazardous constituents, concentration limits, point of compliance, and compliance period; the numerical concentration limit may be based upon the background concentration of a constituent, Maximum Concentration Limits (MCL) for the constituents in the Groundwater Protection Standards, or an Alternate Concentration Limit (ACL) based upon a variance demonstrating no adverse affect on human health and the environment

- method for determining compliance; based either upon single-point-in-time comparison of upgradient and downgradient samples or statistical comparison of downgradient samples against a set of background samples pooled over time

- actions which can be taken when a statistically significant detrimental change from initial background values has been detected (verification of result, proof of contribution by another source).

In the corrective action program, the regulations do not specify the remedial measures should the groundwater protection standards be exceeded. A performance specification rather than a design specification is imposed. Actions to reduce hazardous constituent concentration to meet the concentration limits at the compliance point and clean-up of a contamination plume between the compliance point and facility property boundary are required.

All of these variances or site-specific issues will be addressed and resolved as part of the site permitting process which may be an ongoing activity. Because final specification of requirements lies with the EPA Regional Administrator, it is anticipated that philosophies and policies are likely to differ in the various regional offices. This could be an advantage or disadvantage. However, the regulatory approach does provide for site specific information to be used to formulate the groundwater protection program rather than attempting to mandate a program which effectively addresses all likelihoods in a topic as broad ranging as hazardous waste management. The performance specification approach allows for greater use of technical knowledge possessed by the facility operator and acknowledges the degree-of-risk issue. It, however, must be recognized that in states having primacy for writing facility permits the flexibilities may differ or may not exist at all.

RISK ASSESSMENT

Operators now have a greater opportunity to influence permit conditions for their facilities. To effectively exercise this opportunity, it is necessary to be familiar not only with the regulatory language and techniques for accomplishing groundwater monitoring, but also with methods for developing a technical basis for permit requirements. One approach to developing such a technical basis is performance of a risk assessment. Assessing risk involves determining the probability of an occurrence and the consequences of that occurrence. As it pertains to groundwater monitoring, the focus is more towards examining the consequences once a statistically significant difference from background levels has occurred.

Assessments can vary widely in degree of complexity and confidence of results. The degree of refinement necessary will vary depending upon a number of site-specific factors. In general, to explore the consequences of detection of contamination in a monitoring well the following closely interrelated elements must be examined:

- reactions between migrating contaminants and soils in the area
- contaminant migration direction, extent, rates, and transformations
- hazard of migration to public health and the environment in the pathway of migrating contaminants.

The scope of such an examination could include the following activities:

1. A literature review to identify leachate transformation or attenuation reported in similar soils for the constituents of concern.
2. A review of public agency records to identify water resources and uses which could be affected by migrating leachate.
3. Laboratory bench scale column or sequential leaching tests or field scale lysimeter studies to determine site specific leachate formation and migration parameters.
4. A site water balance to estimate the quantity of leachate produced and potential areas to control leachate production.
5. Explorations characterizing the subsurface and the aquifer and providing the data base necessary to predict leachate movement.
6. Mathematical modeling of leachate transport and physical, chemical, or biological transformations such as attenuation (adsorption, ion exchange, filtration, precipitation), dispersion, and dilution.

EPA Form 2350-4 (4-80)
(PREVIOUSLY CIN: EPA FORM 357)
TYPING GUIDE SHEET

7. Modeling of transport and dispersion in surface waterways predicted to be impacted by leachate migration.

8. Literature review or laboratory testing to determine allowable constituent concentrations in the affected water bodies that would not preclude the intended beneficial uses.

For a new site, many of these activities should be undertaken at the time of site design in order to arrive at a technically suitable, environmentally protective, and cost-effective design.

Having assessed the potential impact on beneficial water uses and public health, a determination can be made with regard to the implications of detection of contamination in the monitoring wells. Risk assessment is a powerful tool which can be used effectively to develop reasoned, technically sound basis for permit requirements for residue disposal operations.

EPA Form 2350-4 (4-80)
(PREVIOUSLY EIN EPA FORM 28*)
TYPING GUIDE SHEET

Although the research described in this paper has been funded wholly or in part by the U.S. Environmental Protection Agency, it has not been subjected to Agency review and therefore does not necessarily reflect the views of the Agency and no official endorsement should be inferred.

RECOVERY OF METALLIC VALUES FROM ELECTRIC ARC FURNACE STEELMAKING DUSTS

by: E. Radha Krishnan and William F. Kemner
PEDCo Environmental, Inc.
11499 Chester Road
Cincinnati, OH

ABSTRACT

Dust generated from electric arc furnaces employed in steel plants is currently listed as a hazardous waste. Disposal of the waste at a controlled landfill is becoming costly as disposal sites become scarcer and more distant from the point of origin. The dust, however, represents a potential source of metals such as iron, zinc, lead, chromium, nickel and molybdenum; recovery or recycling of these metals appears to be a logical alternative to the disposal problem. This paper presents a technical and economic assessment of various technologies available for recovery of metallic values from electric arc furnace (EAF) steelmaking dust.

The type of recovery process which can be employed depends on the chemical composition of the EAF dust, which in turn is dependent on the type of steel product being made. Carbon and low alloy steel EAF dusts are rich in zinc and lead, while dusts from stainless and specialty alloy steels contain significant quantities of chromium, nickel, and molybdenum. Five recovery processes are discussed in this paper: 1) a caustic leach electrolytic zinc recovery process studied in a pilot plant by AMAX Base Metals Research and Development, Inc., in Carteret, New Jersey; 2) the Waelz kiln practice for processing EAF dusts which is being commercially employed by the New Jersey Zinc Company, Inc., in Palmerton, Pennsylvania; 3) an electrothermic shaft furnace process using plasma heat piloted by SKF Steel Engineering in Sweeden and currently being commercialized; 4) a commercial pyrometallurgical smelting technique developed by Inmetco in Ellwood City, Pennsylvania; and 5) a recycling process perfected by the U.S. Bureau of Mines in coordination with Joslyn Stainless Steel Division in Fort Wayne, Indiana.

The AMAX and New Jersey Zinc processes are applicable to recovery of heavy metals, such as zinc and lead, from carbon steel EAF dusts; the SKF process can be applied to both carbon steel and specialty steel dusts to recover metals such as iron, zinc, lead, chromium and nickel; the Inmetco and Bureau of Mines processes are suited to recovery of iron and alloying elements from stainless steel EAF dusts.

INTRODUCTION

Each year the steelmaking industry produces more than 1.8×10^6 metric tons of dusts containing approximately 1×10^6 metric tons of iron, 90,000 metric tons of zinc, 9,000 metric tons of lead, 2000 metric tons of chromium, 500 metric tons of nickel, and 100 metric tons of molybdenum,[1,2] These dusts originate from different types of steel furnaces such as open hearths (OH), basic oxygen furnaces (BOF), and electric arc furnaces (EAF). Although the amount of dust generated from the furnaces at any one steel plant is relatively small, the cumulative quantity is large and represents a significant loss of heavy metals and scarce alloying elements.

In the electric arc furnace, approximately 1 to 2 percent of each charge is converted to dust or fume, which is collected in scrubbers or baghouses.[3] The chemical composition of the dust depends on the type of steel product being made, as shown in Table 1. Carbon steel EAF dusts tend to be richer in zinc and lead because of the greater use of galvanized and other coated products in the melt.[4] On the other hand, alloying elements such as chromium, nickel and molybdenum are prominent in dusts from stainless steel and specialty alloy furnaces. Electric furnaces account for about 25 percent of domestic steel production, and the total zinc in EAF dust generated in the United States is estimated to be around 75,000 metric tons per year.[5]

EAF dust is currently listed as a hazardous waste (Federal Register, Vol. 45, No. 98, Section 261.32, page 33124) because of the leachability of its toxic constituents (Pb, Cd, and Cr^{+6}). Its EPA-assigned hazardous waste number is K061. As a hazardous waste, the dust must be encapsulated or transported to a controlled landfill. Disposal is, however, becoming a costly affair as disposal sites become scarcer and more distant from the point of origin. Disposal costs of \$50 to \$100 per metric ton of dust are quite common. This has led the steelmaking industry to look to other viable options for handling the dust.

This dust represents a potential source of valuable elements, the recovery of which appears to be a logical alternative to the disposal problem. This can also augment our domestic supplies of metals such as zinc, chromium, and nickel, which are largely imported at this time. Figure 1 presents an outline of different recovery options for EAF dust. Recycling to the furnaces for possible additional iron recovery could be practiced if the zinc and lead contents of the dust are fairly low. Zinc and lead concentrations are somewhat high, however, especially in carbon steel EAF dusts, and their levels could build up in the furnace. At high concentrations, these metals (as oxides or ferrites) have been found to attack refractories and cause rapid deterioration of linings in blast furnaces[5]; however, this effect has not been proven in electric arc furnaces. This problem does not arise for stainless steel EAF dusts because of the lower concentrations of zinc and lead.

TABLE 1. CHEMICAL COMPOSITION OF DUST FROM ELECTRIC ARC FURNACES[4]

Carbon and low-alloy steels			Stainless steel and specialty alloys		
Element	Wt, %*	Range, %	Element	Wt, %**	Range, %
Al	0.25	0.09-0.53	Al	0.40	0.20-0.60
Ca	4.19	1.85-10.0	Ca	3.91	1.76-6.93
Cd	0.05	0.03-0.15	Cd	0.46	0.006-1.79
Cr	0.22	0.06-0.58	Cr	5.88	2.01-10.1
Cu	0.23	0.06-0.32	Cu	0.62	0.09-1.26
K	0.66	0.06-1.12	K	2.07	0.80-5.07
Mg	1.68	0.77-2.93	Mg	3.78	1.70-4.74
Mn	3.29	2.46-4.60	Mn	3.72	2.36-4.59
Mo	0.02	<0.02-0.08	Mo	1.08	0.37-1.46
Na	0.99	0.29-2.31	Na	2.12	0.47-4.60
Ni	0.04	0.01-0.12	Ni	1.69	0.15-3.34
Pb	2.02	1.09-3.81	Pb	0.52	0.23-0.78
Zn	18.3	11.12-26.9	Zn	4.58	1.77-6.22
Fe (total)	31.3	24.9-46.9	Fe (total)	27.0	22.2-35.5
Fe^{+3}	29.7	20.5-42.8	Fe^{+2}	4.47	0.53-5.90
Fe^{+2}	1.46	<0.01-3.96	Cr^{+6}	0.10	<0.01-0.17
Fe^{0}	0.09	<0.02-0.34	Si	3.38	2.54-3.92
Cr^{+6}	<0.01	<0.01-0.02	Cl	0.81	0.47-1.17
Si	1.81	1.35-2.49	F	2.48	1.36-4.83
Cl	1.11	0.51-2.36	P	0.02	0.01-0.04
F	0.41	0.01-0.88			
P	0.03	0.01-0.88			
SO_4^{--}	0.70				

* Arithmetic averages of dust from seven plants.

** Arithmetic averages of dust from four plants

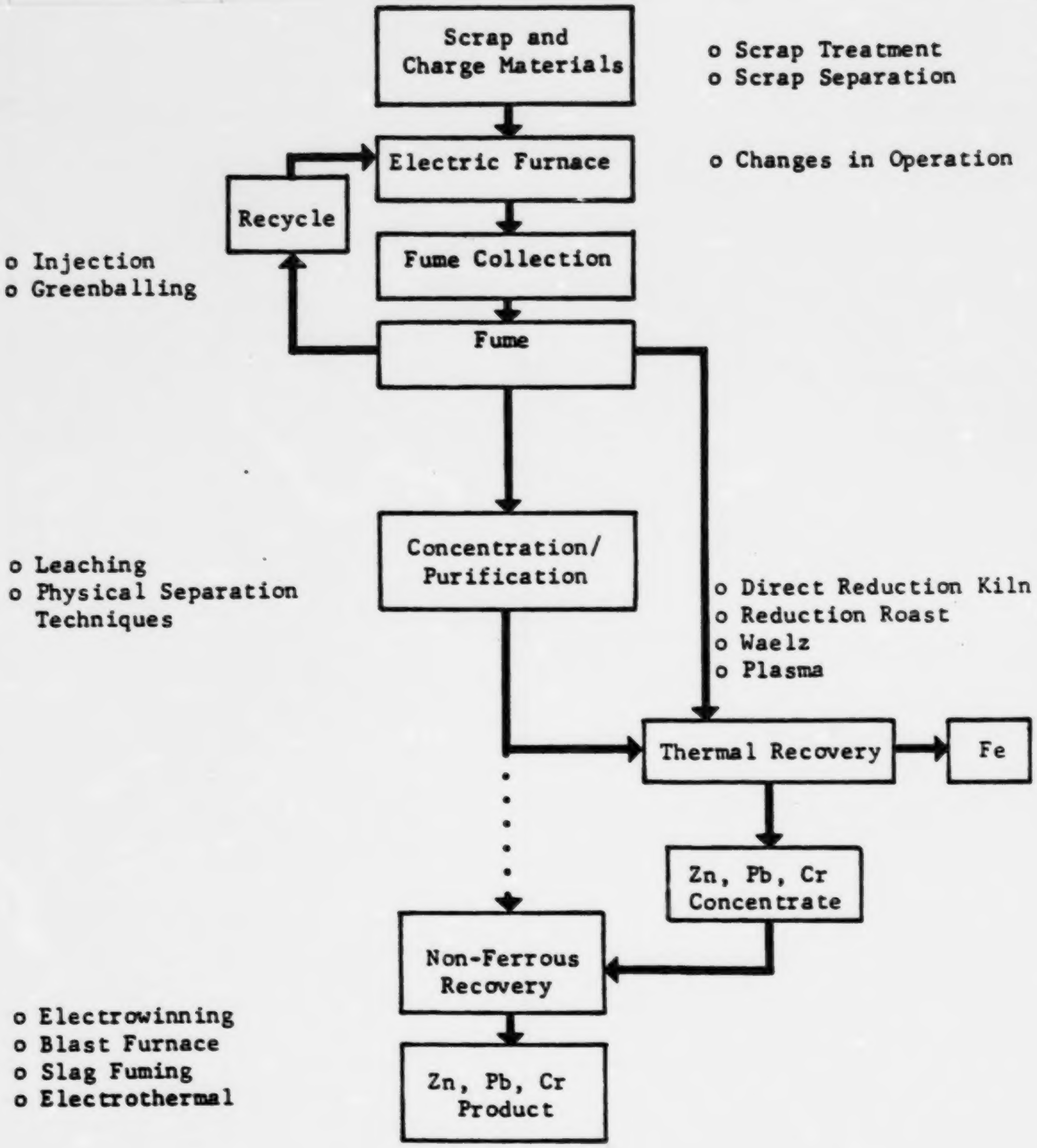

Scrap and Charge Materials
o Scrap Treatment
o Scrap Separation
Electric Furnace
o Changes in Operation
Recycle
Fume Collection
o Injection
o Greenballing
Fume
Concentration/ Purification
o Leaching
o Physical Separation Techniques
o Direct Reduction Kiln
o Reduction Roast
o Waelz
o Plasma
Thermal Recovery
Fe
Zn, Pb, Cr Concentrate
Non-Ferrous Recovery
o Electrowinning
o Blast Furnace
o Slag Fuming
o Electrothermal
Zn, Pb, Cr Product

Figure 1. Options for recovery of resources from electric arc furnace (EAF) dust.[4]

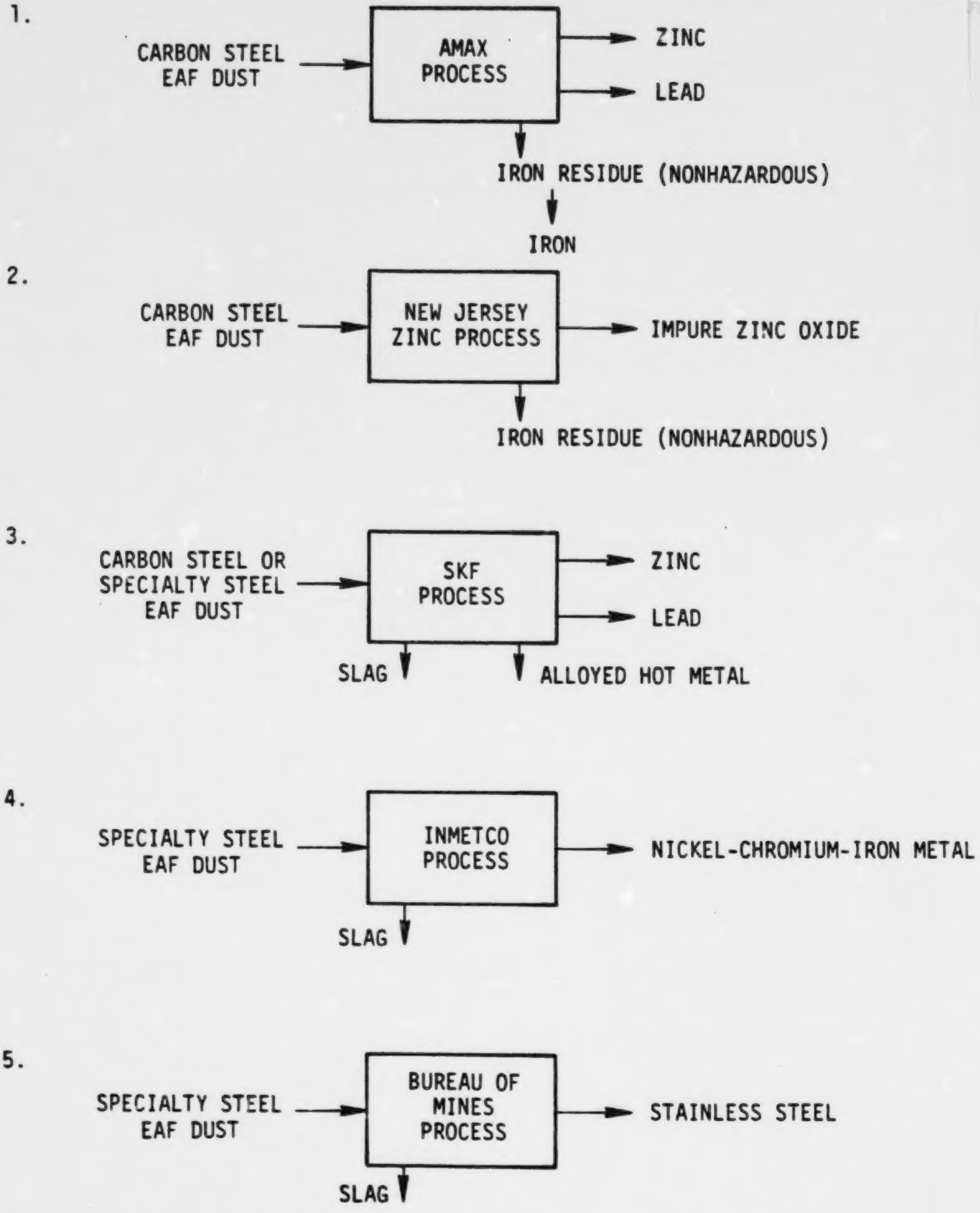
The recovery of nonferrous elements, e.g., zinc, lead, chromium, from EAF dust is another possible alternative. Such recovery could result in a residue that would either have been detoxified for disposal in a landfill or recyclable to the furnace for recovery of iron. When the zinc and lead levels in the dust are not high enough to be of interest, recycling to the furnaces could possibly concentrate the nonferrous elements to a sufficient degree to make the dust attractive for subsequent recovery of these heavy metals. Zinc contents of greater than 15 percent in the dust are generally considered viable for zinc recovery.

The primary operations in nonferrous metals production are ore concentration and smelting. Ore concentration techniques such as flotation are not feasible for treating EAF dust because of the limitations posed by the fine particle size of the dust. Individual particles are generally in the range of 0.1 µm to 1.0 µm.[4] For carbon steel EAF dusts, smelting for zinc recovery is possible with lead being recovered as a byproduct of the smelting operation. The presence of tramp elements such as iron, cadmium, and chlorine in the EAF dust, however, can interfere with the operations encountered in conventional smelting processes. Hence, recovery of nonferrous values from EAF dust requires a separate or add-on smelting facility dedicated to recovery of metals from steelmaking dusts and similar materials. Because limited quantities of steelmaking dust may be generated at any particular plant, the economics will generally require that the recovery process be used on a mixture of dusts from various sources.

This paper discusses five promising technologies that appear to be feasible for recovery of metallic values from EAF dusts. Two of the technologies are applicable to carbon steel dusts, two are suited to stainless and specialty alloy dusts, and one can be applied to dusts produced in the manufacture of both types of steels. Figure 2 presents an overview of the processes.

ASSESSMENT OF PROMISING RECOVERY TECHNOLOGIES

The developers of the five promising technologies (shown in Figure 2) have had some involvement (either at the pilot plant or commercial scale) in recovery of metals from EAF dust or materials similar in composition to the dust. AMAX Base Metals Research and Development, Inc. has investigated a caustic leach electrolytic zinc recovery process in a pilot plant in Carteret, New Jersey; the Waelz kiln practice for processing EAF dusts is being used commercially by the New Jersey Zinc Company, Inc., in Palmerton, Pennsylvania; whereas an electrothermic shaft furnace process using plasma heat has been piloted by SKF Steel Engineering in Sweden, and they are scheduled to place a commercial plant into operation in Landskrona, Sweden, by late 1984. The Inmetco process is currently being applied commercially in the Ellwood City, Pennsylvania, plant on wastes from stainless steel mills; whereas the Bureau of Mines process has been successfully demonstrated in large-scale industrial tests conducted in coordination with Joslyn Stainless Steels in Fort Wayne, Indiana.



1.
CARBON STEEL EAF DUST
AMAX PROCESS
ZINC
LEAD
IRON RESIDUE (NONHAZARDOUS)
IRON
2.
CARBON STEEL EAF DUST
NEW JERSEY ZINC PROCESS
IMPURE ZINC OXIDE
IRON RESIDUE (NONHAZARDOUS)
3.
CARBON STEEL OR SPECIALTY STEEL EAF DUST
SKF PROCESS
ZINC
LEAD
SLAG
ALLOYED HOT METAL
4.
SPECIALTY STEEL EAF DUST
INMETCO PROCESS
NICKEL-CHROMIUM-IRON METAL
SLAG
5.
SPECIALTY STEEL EAF DUST
BUREAU OF MINES PROCESS
STAINLESS STEEL
SLAG

Figure 2. Overview of promising recovery processes for EAF dust.

AMAX CAUSTIC LEACH-ELECTROWIN ZINC PROCESS

AMAX initially studied the caustic leach-electrowin zinc process in a pilot plant to determine the feasibility of recovering zinc from a high-iron zinc ore.[7] With minor modifications, this process can be used to recover zinc from complex zinc oxide-bearing flue dusts such as EAF dust. AMAX has run bench-scale tests on various steel plant residues containing >20 percent zinc and obtained very encouraging results.[8] Because of the limited solubility of iron in caustic, the caustic leach-electrowin zinc process is especially advantageous for recovering zinc from carbon steel EAF dust; the conventional sulfate electrolytic zinc smelting process would be fouled by the iron in the dust. The final product of the process is high-grade zinc (>99.9% Zn) in particulate form.

Figure 3 presents a schematic of the process that AMAX used in their pilot plant to recover zinc from low-grade zinc concentrates. The pilot plant can produce 1360 kg of zinc per day by caustic leaching and subsequent electrolysis of a calcine obtained from a low-grade zinc concentrate with a zinc content greater than 40 percent and an iron content of about 17 percent. In this process, the dead-roasted calcine is first retreated by a kiln-type reduction roast to decompose the zinc ferrite formed during dead roasting and thereby improve the solubility of the zinc. The reduced calcine is then leached in a 30 percent caustic solution; the leach dissolves more than 90 percent of the zinc and lead present and most of the cadmium, but only a very small amount of iron (less than 0.5 percent). The zinc solubilization step can be represented as:

$$ZnO + 2NaOH \rightarrow \underset{\substack{\text{sodium}\\ \text{zincate}}}{Zn(ONa)_2} + H_2O$$

The leach residue obtained after filtration is treated in an electric furnace (lined with burned magnesite brick[9]) to recover copper and precious metals and to produce an oxide dust containing zinc and lead, which is returned to the leaching circuit. The filtrate containing sodium zincate is purified in two steps: 1) aeration to precipitate iron as ferric hydroxide [$Fe(OH)_3$], and 2) cementation with the zinc powder product to remove lead, copper, cadmium, and other metallic impurities that are more noble than zinc. The cake remaining after cementation is separated and processed for lead recovery, whereas the purified solution is electrolyzed to recover pure zinc and to regenerate sodium hydroxide. The electrowinning step can be described by the reaction:

$$Zn(ONa)_2 + H_2O \rightarrow Zn + 2NaOH + 1/2\ O_2$$

Power consumption is approximately 1.2×10^7 J per kg of zinc produced. Makeup caustic required is about 20 kg per metric ton of zinc.[9]

The process variation suggested for treating steelmaking dusts is depicted in Figure 4. For most steel dusts, the reduction roast step is believed to be unnecessary; however, for many carbon steel EAF dusts in which a significant portion of the zinc is tied up as zinc ferrites, reduction roasting with carbon in a neutral atmosphere is essential prior to caustic leach treatment.[9] The iron residue from the leaching circuit is reported to be nonhazardous, and can be landfilled. If desired, metallization of the residue can be carried out in a direct reduction kiln, and the iron product obtained can be recycled to the steel plant. The process can recover over 98 percent of the zinc in the dust.

The AMAX process presents a technically feasible alternative for recovery of metals such as zinc and lead from carbon steel EAF dusts. AMAX is currently performing bench-scale tests on dusts from domestic and European steel companies to determine the applicability of their process to the particular dusts.[9] They believe that economic commercial operation would require a plant capable of producing about 20,000 metric tons of zinc per year.[8] Different types of steelmaking dusts could be combined and processed in a commercial plant.

NEW JERSEY ZINC WAELZ KILN PROCESS

Over the past two years, The New Jersey Zinc Company has intermittently processed carbon steel EAF dusts from various domestic steel plants in their Waelz kilns at Palmerton, Pennsylvania.[10] Using the "American process," the plant also separately processes a zinc silicate ore (franklinite) for zinc oxide production. Approximately 22,000 metric tons of EAF dusts were treated in 1980. The final product obtained by processing the dusts is an impure zinc oxide containing about 50-55 percent zinc and 6 to 7 percent lead. This product is currently stockpiled and will be sold to another smelter for recovery of its metallic value.

The Waelz kiln operation at the New Jersey Zinc smelting facility is similar to the practice at the Berzelius plant in Duisburg, West Germany. The Waelz unit at the latter plant has been processing pelletized EAF dust at a rate of 50,000-55,000 metric tons per year on a full scale since the end of 1977; the process is stated to be economical for zinc contents in the dust of greater than 15 percent.[11] The impure zinc oxide sinter obtained at the plant is processed in an Imperial Smelting shaft furnace for simultaneous recovery of zinc and lead.

A simplified flow diagram of the process used to treat carbon steel EAF dusts at the Palmerton plant is shown in Figure 5, whereas a detailed flow sheet for the "Waelzing" operation is presented in Figure 6. The EAF dusts arrive at the plant by trucks or rail. The facility has a pelletizer for treating dusts that arrive in nonpelletized form. The New Jersey Zinc Company has obtained a permit for storing the material. The pelletized dusts, limestone, and anthracite coal constitute the feed to the kilns. In the kilns, gas flow is countercurrent to solids flow, and the zinc oxide fume and kiln gases are withdrawn at the feed end. The zinc oxide fume, known as Waelz oxide, is cooled by air dilution and collected in baghouses. The Waelz oxide, which typically contains 50 to 55 percent zinc and 6 to 7 percent lead, is the

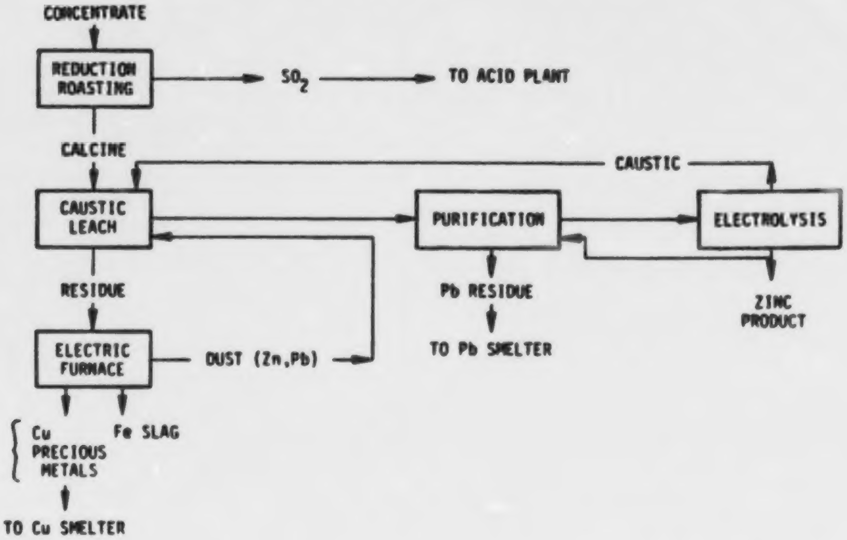

CONCENTRATE
REDUCTION ROASTING
SO2
TO ACID PLANT
CALCINE
CAUSTIC
CAUSTIC LEACH
PURIFICATION
ELECTROLYSIS
RESIDUE
Pb RESIDUE
ZINC PRODUCT
ELECTRIC FURNACE
DUST (Zn,Pb)
TO Pb SMELTER
Cu PRECIOUS METALS
Fe SLAG
TO Cu SMELTER

Figure 3. AMAX process for treating low grade zinc concentrates.[7]

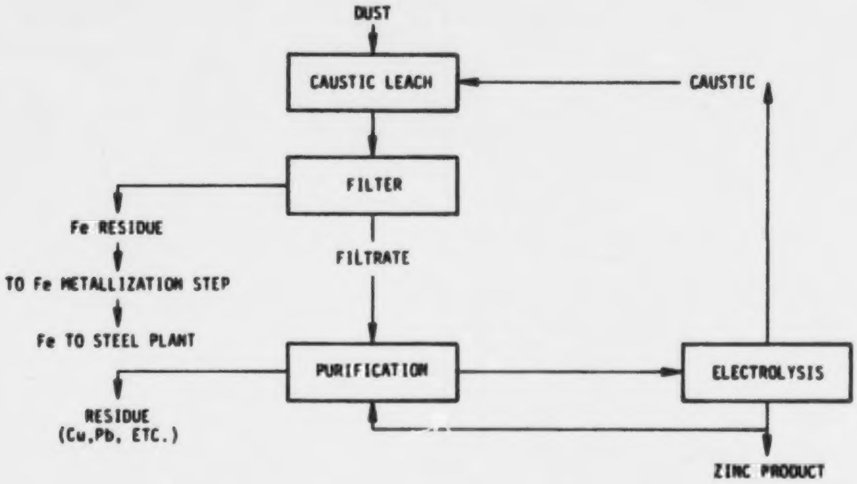

DUST
CAUSTIC LEACH
CAUSTIC
FILTER
Fe RESIDUE
FILTRATE
TO Fe METALLIZATION STEP
Fe TO STEEL PLANT
PURIFICATION
ELECTROLYSIS
RESIDUE (Cu,Pb, ETC.)
ZINC PRODUCT

Figure 4. AMAX process for recovery of zinc from steelmaking dusts.[8]

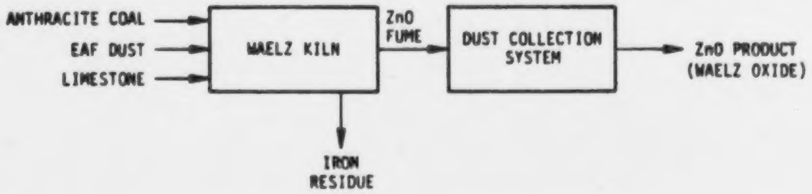

ANTHRACITE COAL
EAF DUST
LIMESTONE
WAELZ KILN
ZnO FUME
DUST COLLECTION SYSTEM
ZnO PRODUCT (WAELZ OXIDE)
IRON RESIDUE

Figure 5. Simplified flow diagram of the New Jersey Zinc Waelz kiln process.

EPA Form 2350-4 (4-80)

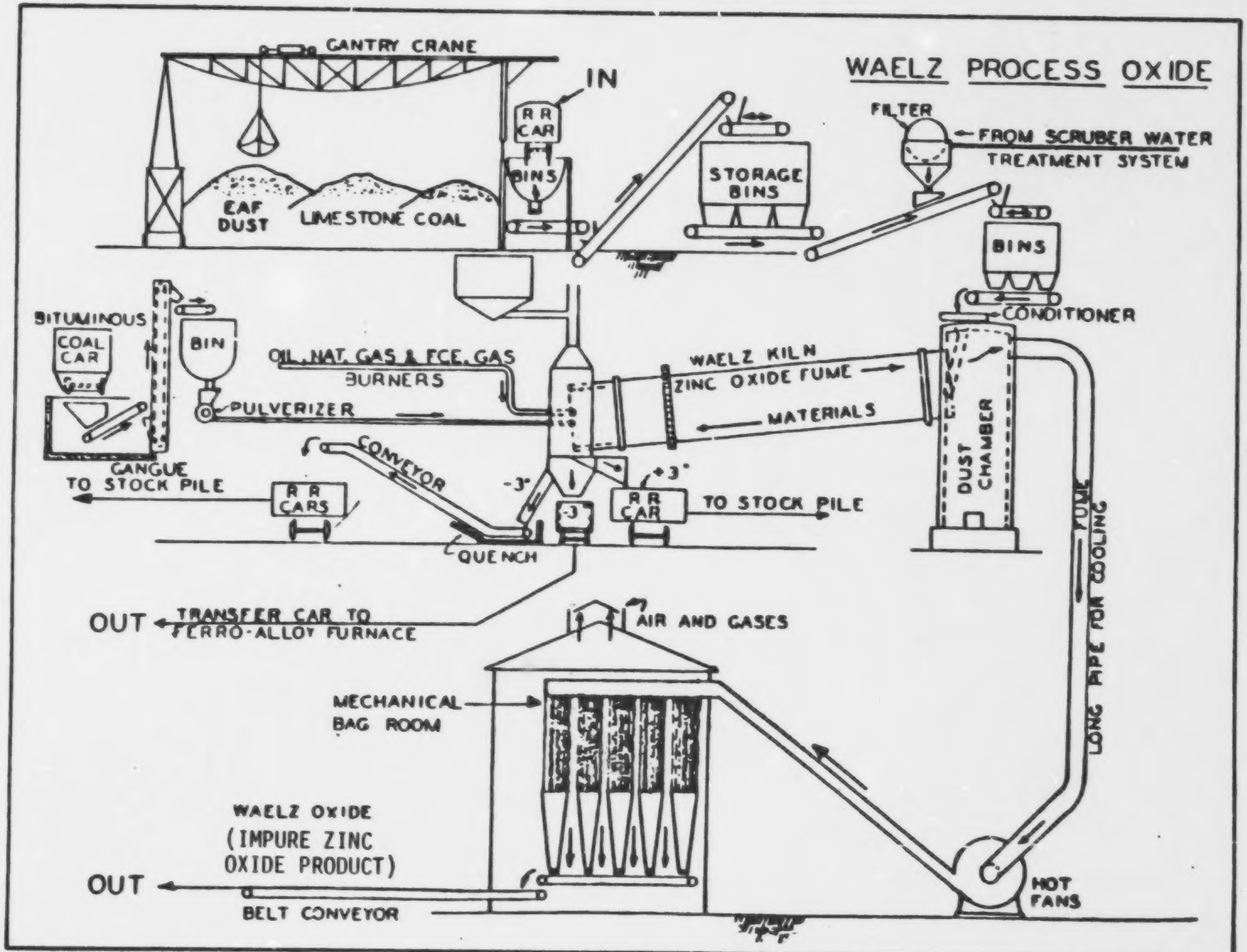

WAELZ PROCESS OXIDE
GANTRY CRANE
IN
R R CAR
BINS
EAF DUST
LIMESTONE COAL
STORAGE BINS
FILTER
FROM SCRUBER WATER TREATMENT SYSTEM
BINS
CONDITIONER
BITUMINOUS
COAL CAR
BIN
OIL, NAT. GAS & FCE. GAS
BURNERS
PULVERIZER
WAELZ KILN
ZINC OXIDE FUME
MATERIALS
DUST CHAMBER
GANGUE TO STOCK PILE
CONVEYOR
R R CARS
-3"
+3"
-3"
R R CAR
TO STOCK PILE
QUENCH
FUME
LONG PIPE FOR COOLING
OUT
TRANSFER CAR TO FERRO-ALLOY FURNACE
AIR AND GASES
MECHANICAL BAG ROOM
WAELZ OXIDE (IMPURE ZINC OXIDE PRODUCT)
OUT
BELT CONVEYOR
HOT FANS

Figure 6. Detailed flow diagram of Waelz kiln operation at the New Jersey Zinc Company, Palmerton, Pennsylvania.

final product and is being sold to another company for recovery of zinc and lead. The residue from the kilns contains only 30 to 40 percent iron and cannot be recycled directly to the steel plant furnaces. Tests conducted by The New Jersey Zinc Company have, however, found the residue to be nonhazardous; therefore, it can be disposed of in a sanitary landfill.

The fee charged by the Palmerton zinc plant for processing of carbon steel EAF dusts from steel plants is a function of the zinc content of the dust. Normally, dusts with zinc contents greater than 20 percent are preferred.

SKF PLASMADUST PROCESS

The PLASMADUST process, which has been developed by SKF Steel Engineering in Sweden, uses a special type of electrothermic shaft furnace to recover zinc, lead, chromium, nickel, molybdenum and iron from EAF steelmaking dusts. The process can be applied to dusts from both carbon steel and specialty steel manufacture. Unlike the Waelz kiln process, which renders an impure zinc oxide concentrate for further reduction to metallic form by thermal or electrolytic methods, the PLASMADUST process produces a zinc vapor that can be directly condensed to liquid metal.[12] The liquid iron tapped from the furnace is alloyed with chromium, nickel and molybdenum when stainless steel dusts are processed.

A flow diagram of the PLASMADUST process is presented in Figure 7. A feed consisting of untreated flue dust, coal powder, and process gas that has been preheated in a plasma arc to about 3500°C is fed into the tuyere level of the shaft furnace. Coke is added from the top to fill the shaft. An endothermic reaction occurs at the bottom of the column between the oxide dust and the reducing agent (coal/coke). The plasma gas, which has a heat content of about 2.0×10^7 J/Nm^3, supplies the heat for the reaction since no oxygen or air is admitted to the furnace. In the reducing atmosphere created by excess coke, carbon monoxide and hydrogen are formed, which rise in the shaft. Most of the suspended particles are caught on the coke surface and eventually returned to the reaction zone. Crude iron (containing the alloying elements) and slag are tapped separately from the bottom of the furnace. Zinc and lead vapors rise with the furnace gases and are condensed and separated in a splash condenser. Since formation of carbon dioxide and water vapor is eliminated because of the reducing atmosphere, the reoxidation risk of zinc and lead vapors is minimized.

The PLASMADUST process has been piloted by SKF Steel Engineering in Sweden. The pilot plant, which is capable of processing about 300 kg/h of flue dust, has shown an iron yield of 99 percent and zinc and lead yields of greater than 97 percent on a typical carbon steel EAF dust containing 50 percent Fe_2O_3, 25 percent ZnO, and 2 percent PbO. Theoretically, waste oxides with only a few percent zinc are equally well suited for the PLASMADUST process, the main technical requirement being that they be sufficiently dry and fine to allow for pneumatic feeding. The economic lower limit, however, is estimated to be about 10 percent zinc.[12] Carbon steel EAF dusts, which typically have zinc levels of 15 to 25 percent and lead levels of 1 to 4 percent, are especially attractive raw materials for treatment by this process.

A commercial plant using the SKF process and having a capacity of 70,000 metric tons of dust per year is scheduled to be placed into operation at Landskrona in southwest Sweden by late 1984.[13] Baghouse dust from steel mills in Sweden and other Scandinavian countries will form the raw material to the plant; metals recovered will include iron, zinc, lead, chromium, nickel and molybdenum. Heat recovered from the plant will be used by the Landskrona municipality for district heating and other purposes.

SKF Steel Engineering is currently looking into the possibility of constructing commercial plants in the United States. The promoters of the SKF process (SiAR, Inc., Cambridge, Massachusetts), believe that Pittsburgh or Chicago would be good locations for such plants because of the concentration of steelworks in those districts.[14] A supply of at least 50,000 metric tons of dust per year from neighboring sources would be required for economic operation of a plant.

INMETCO PROCESS

The Inmetco process as applied in the Ellwood City, Pennsylvania facility treats approximately 110 metric tons of wastes per day from stainless and specialty steel mills to produce 60 metric tons per day of a nickel-chromium-iron pig which is sold back to the steel mills as a melting feedstock.[15] Over three years of operating experience has proven that the Inmetco process is viable and profitable. The Inmetco plant which serves the majority of the specialty steel mills in the eastern part of the U.S. receives three major types of wastes: EAF dust, mill scale, and grinding swarf. Typical compositions of the raw materials are shown in Table 2. Typically, 50 percent of the feed is EAF dust.

TABLE 2. CHEMICAL COMPOSITION OF WASTES RECEIVED AT THE INMETCO PLANT[15]

Type of waste	Range, wt. %				
	Cr	Ni	Mo	Zn	Cu
EAF dust	2.2-19.1	1.0-5.4	0.1-1.0	0.7-2.0	0.2-1.7
Mill scale	7.8-13.1	1.3-4.1	0.1-0.4	-	0.1-1.4
Grinding swarf	13.4-20.0	4.8-20.1	0.3-1.6	-	0.2-1.4

The major steps in the Inmetco process are 1) feed preparation, blending and pelletizing, 2) reduction, and 3) smelting and casting. Figure 8 is a simplified flow diagram of the Inmetco process.

The EAF dust and the other wastes arrive at the Inmetco facility by truck tankers, and are assigned to storage silos based on their nickel and chromium contents. The materials in the various silos are carefully blended to produce a mix with satisfactory processing characteristics and uniform alloy content. Any deficiency in either nickel or chromium content is made up by adding nickel alloy or ferrochrome. The wastes are combined with coal/coke, lime and water in a pug mill, and the resulting mixture pelletized before undergoing partial reduction in a rotary hearth furnace. A portion of the zinc, lead and halogens contained in the flue dust are exhausted into the off-gas treatment system. The hot, partially metallic, sintered pellets (containing

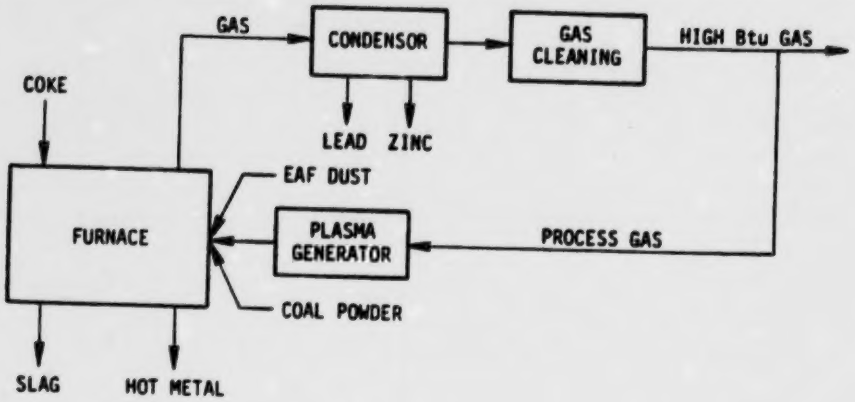

GAS
CONDENSOR
GAS CLEANING
HIGH Btu GAS
COKE
LEAD
ZINC
EAF DUST
FURNACE
PLASMA GENERATOR
PROCESS GAS
COAL POWDER
SLAG
HOT METAL

Figure 7. Simplified flow diagram of the SKF PLASMADUST process.[12]

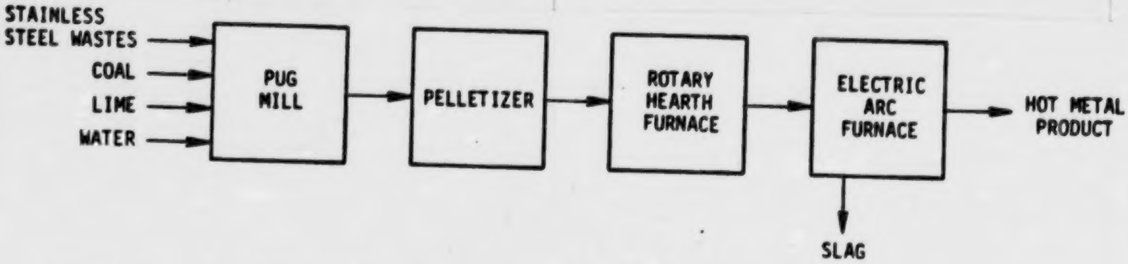

STAINLESS STEEL WASTES
COAL
LIME
WATER
PUG MILL
PELLETIZER
ROTARY HEARTH FURNACE
ELECTRIC ARC FURNACE
HOT METAL PRODUCT
SLAG

Figure 8. Simplified flow diagram of the Inmetco process.

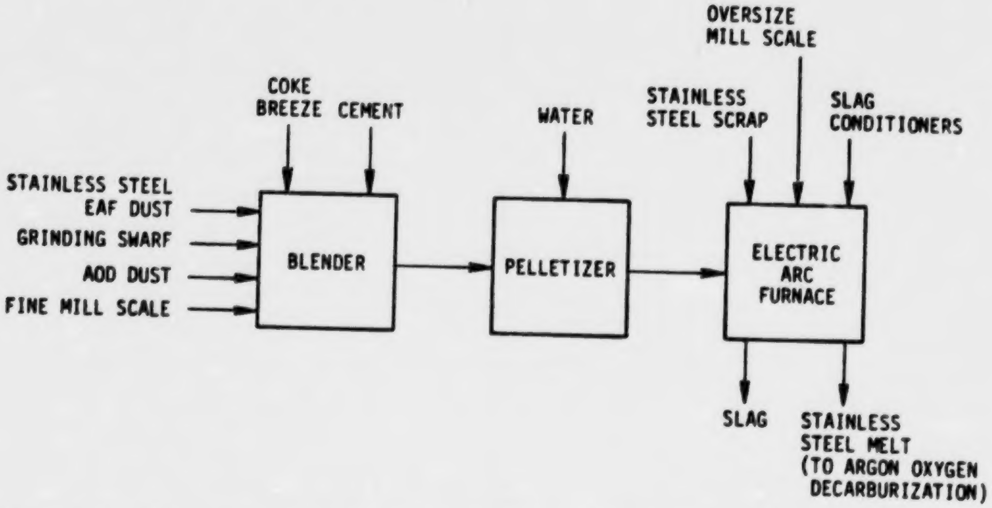

OVERSIZE MILL SCALE
COKE BREEZE
CEMENT
WATER
STAINLESS STEEL SCRAP
SLAG CONDITIONERS
STAINLESS STEEL EAF DUST
GRINDING SWARF
AOD DUST
FINE MILL SCALE
BLENDER
PELLETIZER
ELECTRIC ARC FURNACE
SLAG
STAINLESS STEEL MELT (TO ARGON OXYGEN DECARBURIZATION)

Figure 9. Schematic of Bureau of Mines process for recycling stainless steel wastes.

unreduced chromium oxide) are fed to an electric arc smelting furnace where the pellets are melted and the chromium oxide is reduced by the residual carbon in the pellet. Lime and other siliceous materials form a liquid slag which is tapped separately from the alloyed hot metal. The metal is cast into pigs before being sold. The product typically analyzes 14.0 wt. percent Ni, 14.0 wt. percent Cr and 64.0 wt. percent Fe. Typical metallic recoveries are as follows: Ni-99 percent, Cu-94 percent, Mo-92 percent, Fe-98 percent. The slag is essentially inert and is used locally as fill and road ballast. A wet gas scrubbing system is used to treat the gas emitted from the furnace. The scrubber filter cake which contains ~10 wt. percent Zn is disposed of through a secondary zinc producer.

The operations at Inmetco demonstrate the commercial viability of the process for recovering valuable alloying elements from stainless steel EAF dusts. The composition of the waste materials and the proximity of the waste generator to the Inmetco facility are the factors which can influence the profitability of the process.

BUREAU OF MINES PROCESS

The U.S. Bureau of Mines has developed a recycling process for recovery of alloying elements from stainless steel EAF dusts.[16] The Bureau of Mines technique is similar to the Inmetco process in that different specialty steelmaking wastes are blended, agglomerated on a pelletizer with an addition of a small amount of carbonaceous reducing agent, and charged into a furnace.

After initial laboratory tests indicated that the process had good potential for recovery of metals, a series of larger industrial-scale tests were conducted at Joslyn Stainless Steels in Fort Wayne, Indiana. Figure 9 is a schematic of the Bureau of Mines process. The raw materials which comprised stainless steel EAF dust, argon-oxygen decarburization dust, grinding swarf and mill scale were agglomerated to produce pellets 3/8" to 1" in diameter, analyzing 39.2 wt. percent Fe, 8.9 wt. percent Cr, 3.7 wt. percent Ni and 0.5 wt. percent Mo. The pellets were manufactured by an outside contractor. During the tests, 14 to 19 percent of the charge to the 18-ton electric arc furnaces consisted of pelletized wastes generated at the plant. Stainless steel scrap constituted 80 to 90 percent of the total charge. All the trials produced successful commercial heats of Type 316 stainless steel. Results showed chromium recoveries up to 90 percent, and nickel, iron and molybdenum recoveries of up to 99 percent.[17] Moreover, the heats were routinely produced, and no additional energy or manpower was required.

The Bureau of Mines process may be attractive to specialty steelmaking companies who would wish to practice in-plant recycling.

ECONOMIC EVALUATION

Economics is the governing factor in deciding if any of the metal recovery alternatives are attractive to the steelmaker. Obviously, if the cost of disposing the EAF dust at an off-site hazardous waste landfill is greater than any associated transportation and handling costs incurred in shipping the dust to a recovery plant, recycling/recovery would be worth pursuing by the steelmaker.

The recovery facility owner may wish to pay for transportation of the dust, provided the steel plant is within a reasonable distance from the recovery plant. For example, the New Jersey Zinc Company has previously paid for transportation from sources within 300 miles of their plant. Transportation costs do not arise in the case of the Bureau of Mines process which involves in-plant recycling of the dust.

AMAX and SKF have reported that the capital investment required for a recovery plant capable of treating 70,000 to 100,000 metric tons per year of steelmaking dusts/wastes would be about $20 million.[8,12] New Jersey Zinc also estimates the cost of replacing their Waelz plant to be about $20 million.[10] Table 3 presents our economic evaluation of these three carbon steel EAF dust recovery options for an assumed processing capacity of 90,000 metric tons per year. The evaluation is based on an average dust composition of 30 wt. percent Fe, 24 wt. percent Zn and 2 wt. percent Pb. Our budget estimates show that all the three recovery alternatives could be profitable.

TABLE 3. ECONOMIC EVALUATION OF RECOVERY PROCESSES FOR CARBON STEEL EAF DUSTS*

(Basis: 90,000 metric tons per year capacity plant)

Item	AMAX Electrowin zinc process	New Jersey Zinc Waelz kiln process	SKF PLASMADUST process
Direct Operating costs, $/metric ton of dust	67	72	120
Indirect operating costs, $/metric ton of dust	42	42	42
Transportation costs,** $/metric ton of dust	20	20	20
Total annualized costs, $/metric ton of dust	129	134	182
Product credits, $/metric ton of dust	211	160	251
Profit, $/metric ton of dust	82	26	69

* Based on 1981 cost data.

** Assumed.

No cost data were available for the Inmetco process, although their operation is reported to be profitable. An economic evaluation of the Bureau of Mines process has been conducted;[18] a profit of about $130 per metric ton of agglomerated waste is estimated based on a plant designed to smelt 5 metric tons per day of pelletized wastes.

CONCLUSIONS

Several promising technologies have been developed at either pilot or commercial scales which offer technically feasible routes for recovery of metallic values from electric arc furnace steelmaking dusts. With the exception of the Bureau of Mines process which allows in-plant recycling of the EAF dust, all the other processes require that EAF dusts and other compatible wastes from different steel companies be shipped to a centralized processing facility. Economic operation of the facility requires that the steel plants be in close proximity to the recovery facility. The New Jersey Zinc Waelz kiln plant in Palmerton, Pennsylvania, and the Inmetco plant in Ellwood City, Pennsylvania are the two commercial recovery facilities currently in operation.

Recovery of metallic values from EAF dust offers several benefits. Firstly, it eliminates the disposal costs involved in landfilling the hazardous waste. In-plant recycling has the added advantage of reducing the steel producer's cost by not wasting expensive materials. Further, the recovery technologies can help reduce the nation's demand for imports of chromium, zinc and other critical metals.

ACKNOWLEDGMENTS

The authors would like to thank the following people for providing invaluable information for this study: N. H. Keyser, Consultant, Hinsdale, Illinois; W. R. Opie and H. P. Rajcevic, AMAX Base Metals Research and Development, Inc., Carteret, New Jersey; P. L. Kern and M. R. Silvestris, The New Jersey Zinc Company, Inc., Palmerton, Pennsylvania; P. Baumann, SiAR, Inc., Cambridge, Massachusetts.

REFERENCES

1. Barnard, P. G., A. G. Starliper, W. M. Dressel, and M. M. Fine. "Recycling of Steelmaking Dusts," U.S. Department of the Interior, Bureau of Mines, TPR 52, February 1972.

2. Powell, H. E., W. M. Dressel, and R. L. Crosby. "Converting Stainless Steel Furnace Flue Dusts and Wastes to a Recyclable Alloy," U.S. Department of the Interior, Bureau of Mines, Report of Investigations 8039, 1975.

3. Higley, L. W., and H. H. Fukubayashi. "Method for Recovery of Zinc and Lead from Electric Furnace Steelmaking Dusts," U.S. Department of the Interior, Bureau of Mines, a paper in the Proceedings of the Fourth Mineral Waste Utilization Symposium, Chicago, Illinois, May 7-8, 1974.

4. Keyser, N. H., J. R. Porter, A. J. Valentino, M. P. Harmer, and J. I. Goldstein. "Characterization, Recovery and Recycling of Electric Arc Furnace Dust," presented at the Symposium of Iron and Steel Pollution Abatement Technology for 1981, Chicago, Illinois, October 6-8, 1981.

5. Metal Market 1981. Red Book of Annual Statistics (1980 Data).

6. Higley, L. W., and M. M. Fine. "Electric Furnace Steelmaking Dusts - A Zinc Raw Material," U.S. Department of the Interior, Bureau of Mines, Report of Investigations 8209, 1977.

7. Anderson, W. W., H. P. Rajcevic, and W. R. Opie. "Pilot Plant Operation of the Caustic Leach-Electrowin Zinc Process," TMS Paper Selection, A81-52, The Metallurgical Society of AIME, Warrendale, Pennsylvania 15086.

8. Opie, W. R., Director, AMAX Base Metals Research and Development, Inc., Carteret, New Jersey. December 14, 1981, personal communication.

9. Rajcevic, H. P., AMAX Base Metals Research and Development, Inc., Carteret, New Jersey. March 24, 1982, personal communication.

10. Kern, P. L., Director of Manufacturing and Technical Services, and M. R. Silvestris, Environmental Control Engineer, The New Jersey Zinc Company, Inc., Palmerton, Pennsylvania. December 15, 1981, personal communication.

11. Maczek, H., and R. Kola. "Recovery of Zinc and Lead from Electric-Furnace Steelmaking Dust at Berzelius," Journal of Metals, p. 53-58, January 1980.

12. Herlitz, H. G., SKF Steel Engineering AB, Hofors, Sweden. "The PLASMADUST Process for Recovery of Metals from Waste Oxides," presented at the Symposium on Resource Recovery and Environmental Issues of Industrial Solid Wastes, Gatlinburg, Tennessee, October 28-30, 1981.

13. Herlitz, H. G. "SKF Steel Engineering Bulletin," published by SKF Steel Engineering AB, Hofors, Sweden, June 1982.

14. Baumann, P., SiAR, Inc., Cambridge, Massachusetts. November 30, 1981, personal communication.

15. Hanewald, R. H., J. K. Pargeter, and J. A. MacDougall. "Agglomeration and the Inmetco Process," paper provided by Inmetco, Ellwood City, Pennsylvania. 1982.

16. Higley, Jr., L. W., L. A. Neumeier, M. M. Fine, and J. C. Hartman. "Stainless Steel Waste Recovery System Perfected by Bureau of Mines Research," 33 Metal Producing, November 1979.

17. Bureau of Mines, U.S. Department of the Interior. "In-Plant Recycling of Stainless and Specialty Steel Wastes," Technology News, No. 91, January 1981.

18. Barnard, P. G., W. M. Dressel, and M. M. Fine. "Arc Furnace Recycling of Chromium-Nickel from Stainless Steel Wastes," U.S. Department of the Interior, Bureau of Mines, Report of Investigations 8218, 1977.

The work described in this paper was not funded by the U.S. Environmental Protection Agency. The contents do not necessarily reflect the views of the Agency and no official endorsement should be inferred.

MILL SCALE DE-OILING BY CRITICAL-FLUID EXTRACTION

by: Thomas J. Cody, Jr.
Richard P. de Filippi
Christopher P. Eppig
Critical Fluid Systems, Inc.
An Arthur D. Little Company
Cambridge, MA

ABSTRACT

A process for de-oiling mill scale with critical-fluid solvents (liquefied gases or supercritical fluids) has been successful in bench-scale tests. A process design and evaluation has been completed, and preliminary economic estimates for both capital and operating costs appear promising. Additional testing for final process definition is expected to be concluded in several months.

MILL-SCALE DE-OILING

INCENTIVES FOR DE-OILING

In steel mills, mill scale amounts to 4% to 5% of the total raw steel production. Its oil content is varied, but can run as high as several percent for the composite scale for a total mill, and much higher for certain specific operations. Chemically, the solids are largely iron oxides, and the oils can be mineral oils or fats and fatty oils typically used as lubricants in rolling mills.

A 1978 study (1) showed that about half the mill scale produced is recycled to sinter plants for return to the blast furnace; the other half is stockpiled. The same study showed that about 11% of all lubricants purchased by steel mills ultimately becomes the oil fraction of mill scale.

Coarse mill scale (+5mm) has a low oil content(2), and may be recycled as a direct metallic charge to the blast furnace. Mill scale fines (-5mm), which are 80% to 85% of the total mill scale, have an oil content sufficiently high to adversely effect sinter plant operations. The oil is volatilized during sintering and recondenses in the sinter-plant off-gas. Without treatment, the gaseous effluent can produce a visible plume; where bag houses are used, the oil can condense and impair the operation.

Tests have shown(2) that the maximum tolerable content of oily mill scale in the sinter-plant charge is about 7%. In facilities where de-oiling of mill-scale fines is carried out, the sinter-plant charge can accept at least 25-30% of this material as feed. Therefore, major gains in mill-scale recovery can be made with de-oiling, coupled with the elimination of very substantial quantities of solid wastes.

DE-OILING METHODS

Several de-oiling methods have been tested, and some have been put into commercial use.

Water washing using hot alkaline solution can remove the majority of oil on mill-scale fines. The method has the advantage of low cost. However, at best, 5% to 10% of the initial oil remains on the mill scale.

Thermal incineration methods have been tested, and a direct-fired kiln has been reported in commercial use(2). The principal advantage of incineration is high percentage removal of oil. The major disadvantage is high fuel cost, which includes treatment of the kiln off-gas by after-burning.

Consideration has been given to the use of liquid solvent washing, in which a chlorinated hydrocarbon solvent is used to extract the oil from mill-scale fines, and then distilled to recover the solvent. While no details are available, this method would seem to have the advantage of recovering the oil fraction for use as fuel, or even for recycle as a lubricant. Energy costs for solvent distillation may be high, and residual solvent on the de-oiled fines would have to be evaluated.

A new solvent washing process is in the final stages of development, using condensed gases (critical fluids) as the solvent. This process appears to offer the advantage of oil recovery, low-energy costs, and solvent-free de-oiled mill-scale fines. Process information is given in this paper.

CRITICAL-FLUID EXTRACTION

Critical-fluid extraction refers to the use of fluids which are gases at ambient temperature and pressure, but which become good solvents when compressed to liquids (i.e., at pressures below the critical pressure) or supercritical fluids (at pressures above the critical pressure). Those regimes are shown in Figure 1, which is a generalized reduced pressure-temperature-density map. Supercritical fluids (SCF) are in the range of reduced pressures (actual pressured divided by critical pressure) of 1.0 to 5.0, and reduced temperatures of 1.0 to about 1.4. Much above these pressures, costs become uneconomical because of equipment and compression requirements; at temperatures above this range, densities become low, and attendant solubilities of solutes in supercritical fluids decrease drastically.

A near-critical liquid (NCL) refers to conditions near but below the critical temperature, and a range of pressures around the critical pressure. Generally, there is a continuity of properties within the complete supercritical and near-critical liquid regimes, with no abrupt changes occurring across the critical pressure or temperature.

In these regimes, fluids possess high solubilities much like liquid solvents because of high densities (specific gravities of 0.2-0.7). In addition, kinetic properties such as diffusion coefficient and viscosity are quite favorable: diffusion coefficients are higher and viscosities are lower than for ordinary liquids. Some generalized properties are summarized in Table 1.

Some fluids which have been described in the literature as effective critical-fluid solvents are listed in Table 2. Carbon dioxide has been considered in many cases because of its low cost and non-hazardous chemical

EPA Form 2350-4 (4-80)
(PREVIOUSLY CIN. EPA FORM 37)
TYPING GUIDE SHEET

BEGIN FIRST LINE OF TEXT HERE
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD: BEGIN SECTIONS HERE

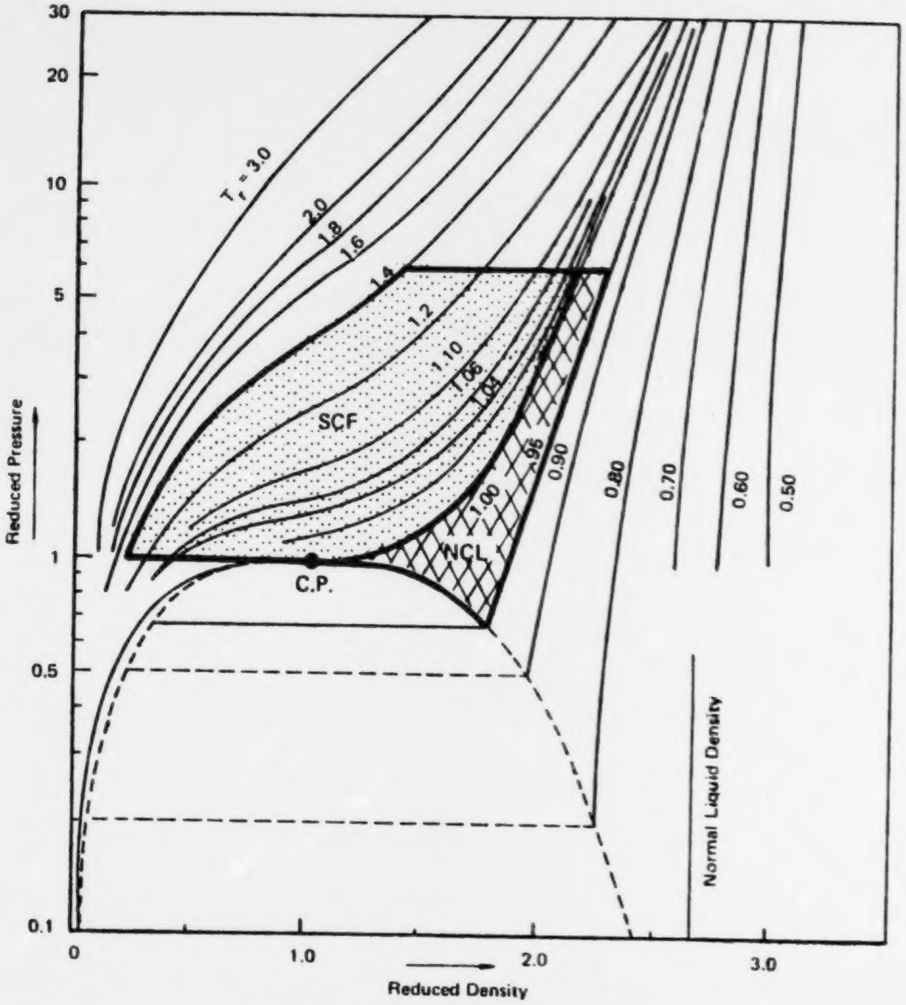


Figure 1. Reduced Pressure-Density Diagram. Supercritical Fluid (SCF) and Near Critical Liquid (NCL) Regions, as Indicated

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA, OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

EPA Form 2350-4 (4-80)
(PREVIOUSLY EIN. EPA FORM 237)
TYPING GUIDE SHEET

TABLE 1. COMPARISON OF CRITICAL-FLUID PROPERTIES

	LIQUID	SUPERCRITICAL	GAS
DENSITY, g/cm^3	1.0	0.2 - 0.7	0.001
VISCOSITY, CENTIPOISES	0.5 - 1.0	0.05 - 0.10	0.01
DIFFUSIVITY, cm^2/sec	10^{-5}	10^{-4} - 10^{-3}	10^{-1}

TABLE 2. CRITICAL PROPERTIES FOR SELECTED FLUIDS

FLUID	T_c °C	P_c,atm	ρ_c,g/cm^3
Ethane	32.3	48.8	0.203
Propane	96.9	42.6	0.220
Butane	152.0	38.0	0.228
Pentane	296.7	33.8	0.232
Ethylene	9.9	51.2	0.227
Ammonia	132.4	112.8	0.235
Carbon Dioxide	31.1	73.8	0.468
Sulfur Dioxide	157.6	78.8	0.525
Water	374.3	221.1	0.326

nature. Hydrocarbons have also been considered, often because of superior solubilities for organic materials. Another group, not shown, includes the halocarbons, such as chlorofluoro methanes and ethanes.

EXTRACTION OF OILY SOLID WASTE

BENCH-SCALE EVALUATIONS

A series of bench-scale experimental evaluations has been carried out on several different oily solid wastes. In each case, the objective was to extract petroleum-based oils or triglycerides from mineral solids, to produce an essentially oil-free solid and to recover the oil phase.

The bench-scale equipment used for testing extractions is shown in Figure 2. Oil-laden solids are charged to an extraction vessel, typically holding 0.25 to 0.5 lbs of material. Liquefied gas or supercritical fluid is pumped up to extraction pressures, which range from 200 psia to 2500 psia depending on the fluid employed. Temperatures are typically near ambient. In the experimental unit, solvent flow is once through, and the extract leaving the extraction vessel is let down in pressure to atmospheric, at which point the oil separates out as a liquid phase. Quantity of gas solvent and oil are measured to determine extract concentrations. Flow rate, temperature, and pressure can be varied to assess the extraction kinetics.

Table 3 summarizes data from two other separations of oils from mineral solids: triglycerides from clay solids, and diesel oil from oil-well drill cuttings. Both feeds were extracted with halocarbon and hydrocarbon solvents, and with carbon dioxide.

Triglycerides are much more readily extracted with the halocarbon/hydrocarbon solvents than with CO_2. High CO_2 pressures are required for it to be an effective solvent, and relatively large solvent quantities are required. Diesel oil is more easily extracted with each solvent, compared to triglycerides.

Table 4 gives a summary of a series of runs made from de-oiling mill scales. Two different mill-scale samples were obtained from stockpiled material: about 3.7% oil, and 1.0% oil. The respective water contents were approximately 0.8% and 1.3%.

Results are shown for hydrocarbon and halocarbon solvents, which gave similar extractibility, and for carbon dioxide. The hydrocarbon and halocarbon extractions were carried out at about 700 psia; this high pressure was maintained to assure that the solvent would remain condensed in the experimental system, where pressure fluctuations occur due to pump cycling, and where the solution is sometimes heated so that there will be no oil precipitation in the small-diameter lines and valves in the laboratory set-up. Actual extractions may be carried out at pressures on the order of

EPA Form 2350-4 (4-80)
(PREVIOUSLY CIN. EPA FORM 387)
TYPING GUIDE SHEET

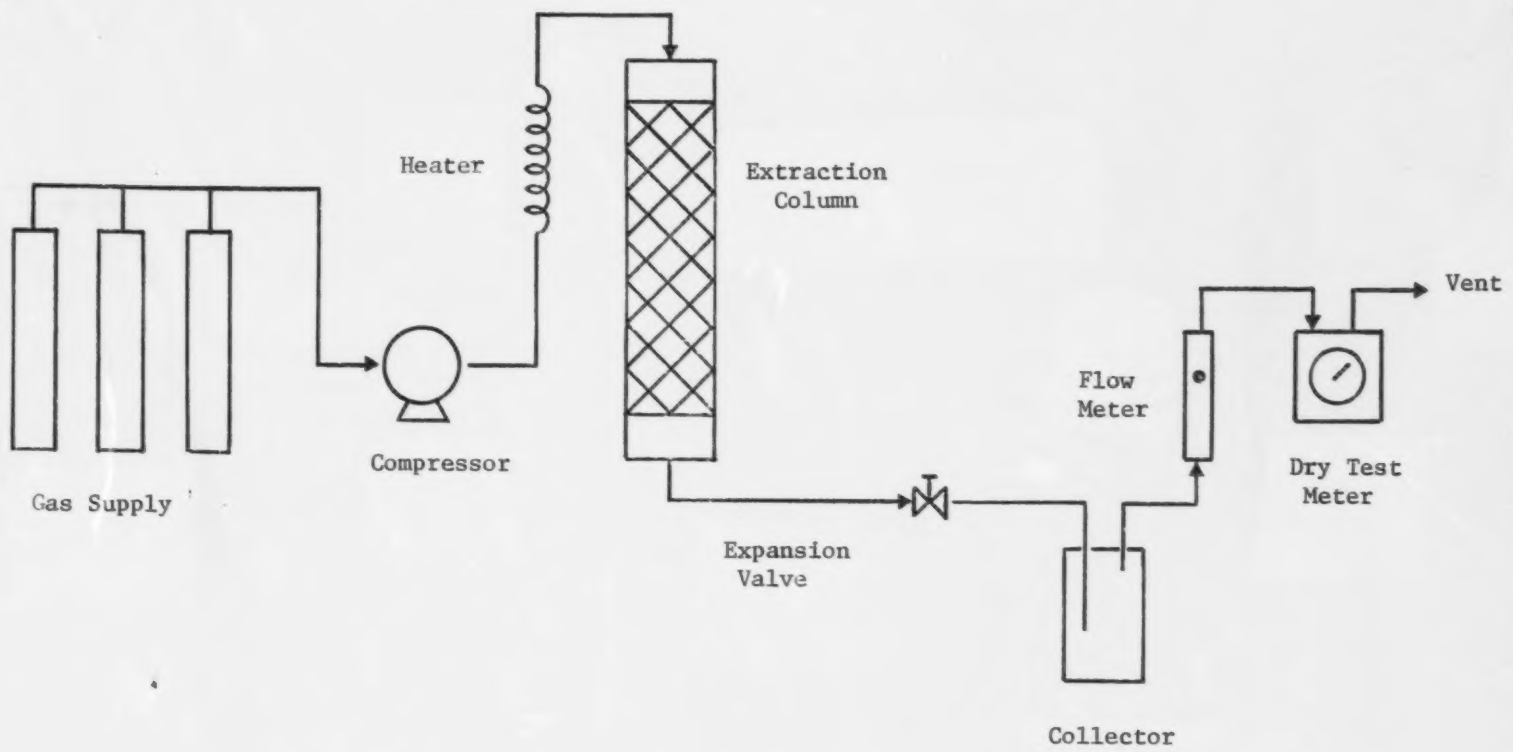

Heater
Extraction Column
Vent
Flow Meter
Gas Supply
Compressor
Dry Test Meter
Expansion Valve
Collector

Figure 2. Benchscale Test Equipment

TABLE 3. DE-OILING OF MINERAL SOLIDS

FEED	WEIGHT % OIL	SOLVENT	PRESSURE, Psia	TEMP, °F	SOLVENT/FEED RATIO	OIL EXTRACTED, WT % OF FEED
Triglycerides from clay	39.6	Halocarbon/ Hydrocarbon	150	74	8.4	40.4
Triglycerides from clay	31.4	Carbon Dioxide	2000	68	164	27.7
Diesel oil from crushed drill cuttings	10.8	Halocarbon/ Hydrocarbon	850	140	2.8	10.6
Diesel oil from crushed drill cuttings	9.9	Carbon Dioxide	2150	99	3.7	9.9

EPA Form 2350-4 (4-80)
(PREVIOUSLY CIN. EPA FORM 287)
TYPING GUIDE SHEET

TABLE 4. MILL-SCALE DE-OILING BENCH-SCALE TESTS

SOLVENT	PRESSURE, Psia	TEMP, ^{o}F	SOLVENT/FEED RATIO	SAMPLE WT % OIL	SAMPLE WT % WATER	% OF FEED EXTRACTED AS: OIL	% OF FEED EXTRACTED AS: WATER
Hydrocarbon/ Halocarbon	700	75	0.32	3.7	0.8	3.7	0.04
Hydrocarbon/ Halocarbon	700	75	1.4	1.0	1.3	1.0	0.12
Carbon Dioxide	2200	120	17	1.0	1.3	0.9	1.3

EPA Form 2350-4 (4-80)
(PREVIOUSLY CIN: EPA FORM 247)
TYPING GUIDE SHEET

200 psia. Solvent-to-feed weight ratio between 0.3 and 1.4 were used, and in the case of both mill scale samples, essentially complete oil removal was achieved. Because of the low solubility of water in the solvent, water removal was incomplete, and the residual mill scale retained some moisture.

Carbon dioxide was run at 2200 psi and 120°F, with a solvent/feed ratio of 17. Even at this high solvent use, there was incomplete oil removal, although the sample was completely dried of water. The comparative oil extractions are typical, in that carbon dioxide generally has a lower solubility for triglycerides and mineral oils than the hydrocarbon and halocarbon solvents.

PROCESS DESIGN AND ECONOMICS

Figure 3 shows an overall flow diagram for the process. The process system contains two parallel extractor columns, which are used alternately: one being in the solvent circulation loop for mill-scale de-oiling, and the other being discharged of de-oiled solid, and recharged with oily solids. The solvent circulation is continuous, while the solids are handled in batches alternating between the two vessels.

Solids may be charged to the extractors in a slurry with additional oil, most of which is displaced from the extractor with the initial introduction of solvent. The slurry oil is taken from a portion of the extracted oil and recycled to a slurry tank.

Solvent is separated from oil and recycled to the extractor. Separation is carried out by vapor-recompression evaporation, which greatly reduces the energy requirement for the system, and is facilitated by the very high volatility of the solvent. In this way, oil can be stripped to very low levels of residual solvent, and the extracted solids are solvent-free.

Table 5 summarizes estimated process economics. The base case evaluated is for a system handling 25,000 lbs/hr (11.4 long tons/hr) of oily mill scale, with feed oil content up to 5%. The principal operating cost is labor, since energy and solvent make-up costs are low. The estimated total processing cost, including capital-related costs is about $6/long ton.

CONCLUSIONS

Bench-scale experimental evaluations and engineering and economic studies have shown that mill scale can be de-oiled with a critical-fluid solvent extraction process. Mill scales with oil contents from 1-4% have been tested, and operating economics appear favorable.

Further bench-scale testing is currently in progress, which we expect to conclude by January, 1983. We anticipate that process design and economics will be firmed up shortly thereafter.

EPA Form 2350-4 (4-80)
(PREVIOUSLY CIN. EPA FORM 247)
TYPING GUIDE SHEET

BEGIN FIRST LINE OF TEXT HERE
DROPPED HEAD; BEGIN SECTIONS HERE
EGIN LAST LINE OF TEXT

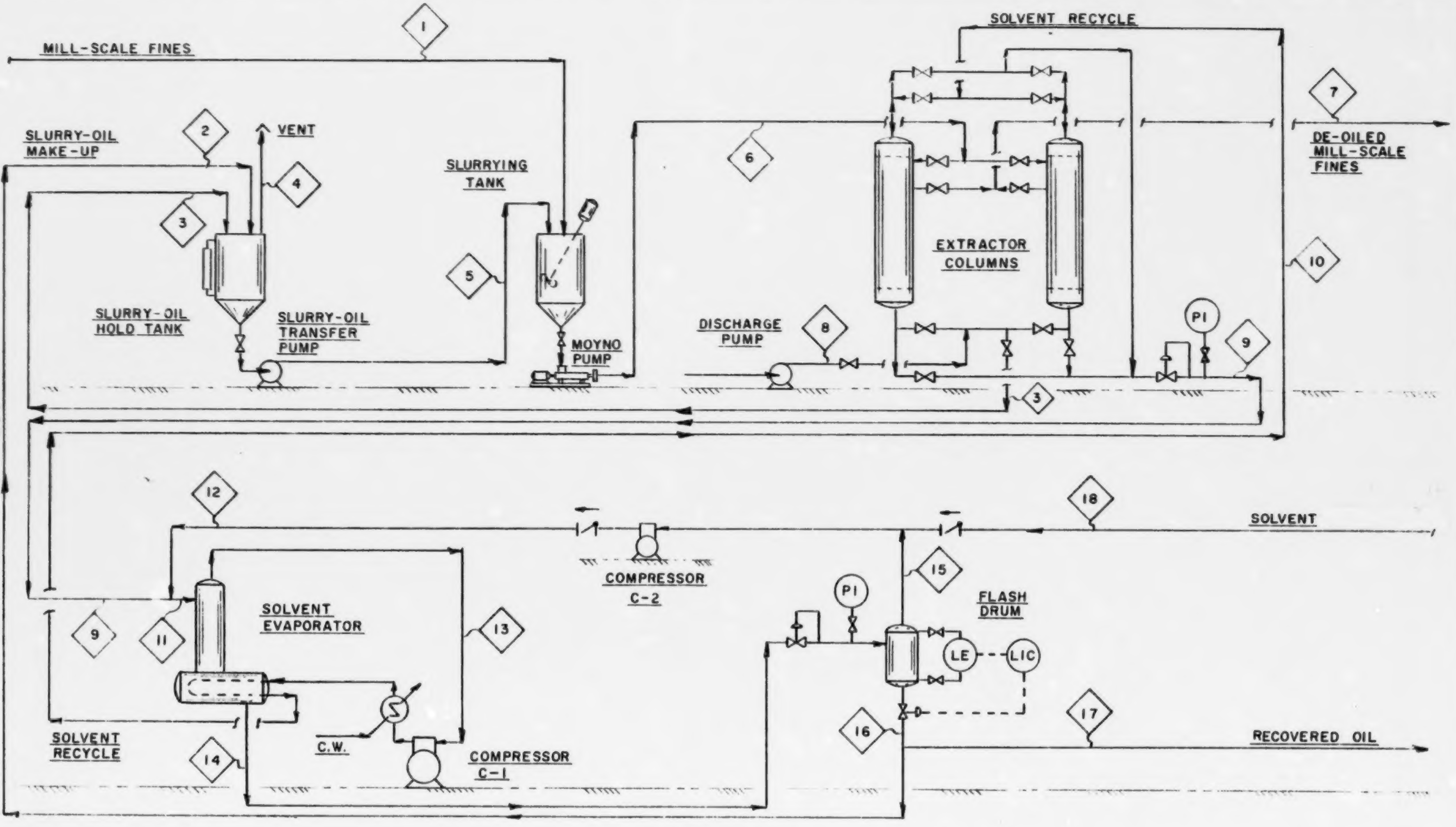

1
MILL-SCALE FINES
SOLVENT RECYCLE
SLURRY-OIL MAKE-UP
2
VENT
4
3
SLURRYING TANK
5
6
7
DE-OILED MILL-SCALE FINES
EXTRACTOR COLUMNS
10
SLURRY-OIL HOLD TANK
SLURRY-OIL TRANSFER PUMP
MOYNO PUMP
DISCHARGE PUMP
8
PI
9
3
12
18
SOLVENT
COMPRESSOR C-2
15
PI
FLASH DRUM
9
11
SOLVENT EVAPORATOR
13
LE
LIC
SOLVENT RECYCLE
14
C.W.
COMPRESSOR C-1
16
17
RECOVERED OIL

Figure 3. FLOW DIAGRAM C.F.S. SOLVENT EXTRACTION SYSTEM FOR MILL-SCALE DE-OILING

CRITICAL FLUID SYSTEMS, INC.

TOP OF MAGE AREA
OTTOM OF MAGE AREA UTSIDE IMENSION OR TABLES ND ILLUS RATIONS

TABLE 5. MILL-SCALE DE-OILING WITH CRITICAL-FLUID EXTRACTION

PRELIMINARY ESTIMATES OF PROCESS COSTS

CAPACITY: 11.4 long tons/hr (25,000 lbs/hr)
8000 hrs/year

CAPITAL COST: $1,300,000

	$/TON
OPERATING COSTS:	
POWER: 300 HP	0.99
MAKEUP SOLVENT: 7.5 lbs/hr	0.46
LABOR + OVERHEAD: 1 man/shift	1.76
	3.21
CAPITAL RELATED:	
DEPRECIATION: 10% of capital	1.43
MAINTENANCE, TAXES, INSURANCE: 10% of capital	1.43
	2.86
TOTAL	6.07

EPA Form 2350-4 (4-80)
(PREVIOUSLY CIR. EPA FORM 681)
TYPING GUIDE SHEET

REFERENCES

(1)Serne, J. C., and K. Wilson, "The Use and Fate of Lubricants, Oils, Greases, and Hydraulic Fluids in the Iron and Steel Industry", EPA Report No. EPA-600/2-78-101, May, 1978.

(2)Balajee, S.R., "De-Oiling and Utilization of Mill Scale", presented at the First EPA Symposium on Iron and Steel Pollution Abatement Technology, Chicago, Nov., 1979.

SESSION 3: AIR POLLUTION ABATEMENT

Chairmen: Murray Greenfield
Environmental Control
Dofasco, Inc.
Hamilton, Ontario, Canada

James R. Zwikl
Environmental Control
Shenango, Inc.
Pittsburgh, PA

Although the research described in this paper has been funded wholly or in part by the Environmental Protection Agency, it has not been subjected to Agency review and, therefore, does not necessarily reflect the views of the Agency and no official endorsement should be inferred.

DETERMINATION OF THE DECAY IN CONTROL EFFICIENCY OF CHEMICAL DUST SUPPRESSANTS ON UNPAVED ROADS

by: Thomas Cuscino, Jr., Gregory E. Muleski, and
Chatten Cowherd, Jr.
Midwest Research Institute
425 Volker Boulevard
Kansas City, Missouri 64110

ABSTRACT

This paper presents the methodology and results of two field studies directed toward the quantification of control efficiency of chemical dust suppressants applied to unpaved roads. Three generic categories of chemical controls were studied: water, a water-based petroleum resin, and a water-based asphalt emulsion. For each dust suppressant studied, the decay in control efficiency with time (or more specifically, with vehicle passes) is presented for a single application intensity, dilution ratio, and vehicle weight and speed distribution. Separate control efficiency curves for total, inhalable, and fine particulate emissions are presented.

It was observed that there is a more than linear increase in control efficiency with an increase in chemical suppressant concentration in the applied liquid. It was also observed that the increased shear stress on the treated road caused by stop and go traffic results in a much more rapid decay in control efficiency than occurs with constant speed traffic. Finally, it is concluded that a single control efficiency value for a chemical dust suppressant is a meaningless value unless the associated vehicle, road, and chemical application (and reapplication) characteristics are specified.

INTRODUCTION

With the advent of the Controlled Trading Program and the inclusion of fugitive dust as a consideration in SIP revisions, much emphasis has been placed on the estimation of the control efficiency achieved by fugitive dust mitigation techniques. Interest has focused on the cost-effectiveness of: (1) chemical dust suppressants, including water, on unpaved roads; (2) paving of unpaved roads; and (3) flushing, broom sweeping and vacuum sweeping of paved roads. This paper will focus on the control of unpaved road emissions within iron and steel plants. Midwest Research Institute (MRI) estimates that this source contributed approximately 54,000 Mg/year (60,000 T/year) or 70% of the suspended open dust generated by the iron and steel industry in 1978, a year which predated the initiation of most major open dust control programs in the industry.[1]

In order to assess the current interest in chemical control of unpaved road dust within the steel industry, a survey was conducted through corporate officials from eight of the largest corporations representing 30 of the 45 major steel plants in the country. The results of this survey representing the year 1981 and the first half of 1982 are shown below. The survey results show a keen general interest in unpaved road control and a specific interest in petroleum resins. The commitment to watering was not surveyed.

Range of interest	Distribution of plant responses				
	Petroleum resins	Asphalt emulsions	Lignin sulfonates	Salts	Total
Committed to use	5	2		3	10
Testing	4		1		5
Considering	5				5
No plans to use chemical controls					10

There are several variables which must be evaluated concomitant with control efficiency if the chemical control performance data obtained at a particular plant test site are to be applied to another plant or another time. The application intensity and the dilution ratio along with the time after application that each controlled test is conducted must be quantified. The number of vehicle passes and the weight distribution during testing and during the total period from initial chemical application through the end of the testing program are also important.

This paper presents control efficiency decay curves from two separate studies performed for the U.S. Environmental Protection Agency (EPA) Industrial Environmental Research Laboratory by MRI. Preliminary results of the initial study were presented in 1982 at two separate conferences.[2,3] The data presented here are based on the final report[1] for the initial study and supercede the two prior papers. This paper also includes preliminary data from the follow-on study which is currently underway.

TEST PROCEDURE AND DESCRIPTION FOR THE INITIAL STUDY

This section presents the test procedure and site description for the initial study. The following topics are discussed: (1) study design; (2) site description; (3) equipment deployment; (4) quality assurance; and (5) control efficiency calculation procedure.

STUDY DESIGN

There are three study designs currently being used to quantify the control efficiency of a chemical dust suppressant applied to an unpaved road:

EPA Form 2350-4 (4-80)
(PREVIOUSLY CIN. EPA FORM 237)

TYPING GUIDE SHEET

1. One or more contiguous road segments are treated, each with a separate chemical, but one of the segments is left untreated. Usually, nonisokinetic sampling devices (such as hi-vols) are placed upwind and downwind of each segment at a single height and are actuated by a wind direction switch. Control efficiency is calculated from the ratio of the net concentrations downwind of the controlled and uncontrolled segments.

2. The same treatment configuration is used as in 1, but the measurement technique is a relative observation technique which compares visual estimates of dustiness of plumes originating from each segment. The results of this design are not quantitative, but simply indicate that one chemical performs better than the others.

3. Uncontrolled tests are performed initially. Then the same configuration is used as in 1, except that there is no untreated segment. The measurement technique is exposure profiling which involves simultaneous isokinetic measurement of concentration at 4 to 5 heights across the plume.

There are several pros and cons for each method above, but a detailed analysis is not appropriate here. Generally, methods 1 and 2 have the problem of track-on of dust from the uncontrolled segment to the controlled segments. Method 2 has an obvious drawback for research purposes in that no quantitative data are produced. Method 3, employed by MRI, has none of the above problems, but does require a normalization of measurement-based emission factor values to allow for differences in vehicle characteristics during the uncontrolled and controlled tests which do not occur simultaneously.

SITE DESCRIPTION

All the uncontrolled and controlled unpaved road tests in the initial study were conducted at Armco's Middletown Plant. Armco instituted an extensive array of control measures at the Middletown Plant effective August 1980. Application of a petroleum resin on many unpaved roads was a part of this program. MRI performed uncontrolled tests for light-duty vehicles traveling on these roads in July 1980, and performed controlled tests in October 1980. Tests of heavy-duty traffic traveling on uncontrolled and watered roads were performed in November 1980 on a previously untreated unpaved road.

EQUIPMENT DEPLOYMENT

Two equipment deployment schemes were employed at Middletown. The basic downwind equipment included an exposure profiling system located 5 m (16 ft) from the edge of the road with either four or five sampling heads spaced vertically 1 m (3.3 ft) apart, and high-volume cascade impactors fitted with cyclone preseparators at 1 m (3.3 ft) and 3 m (9.8 ft) heights. In addition, a standard high-volume air sampler was operated at a height of 2 m (6.6 ft). The upwind air sampling equipment consisted of a standard high-volume air sampler at a height of 2 m (6.6 ft) and either one or two hi-vols fitted with size-selective inlets, operated at 2 m (6.6 ft) or 1 m (3.3 ft) and 3 m (9.8 ft), respectively.

EPA Form 2350-4 (4-80)
(PREVIOUSLY CIN. EPA FORM 283)
TYPING GUIDE SHEET

QUALITY ASSURANCE

The sampling and analysis procedures followed in this field testing program were subject to certain quality assurance guidelines. Affected areas included: (1) auditing procedure for gravimetric analysis of filters; (2) filter handling procedures in the field and laboratory; (3) equipment flow rate calibration technique and frequency; (4) field data recording procedures; (5) standard procedures for physical analysis of road aggregate; and (6) calculation techniques and accuracy. A detailed description of the quality assurance procedures can be found in the final report.[1]

CONTROL EFFICIENCY CALCULATION PROCEDURE

Because of meteorological conditions and logistical constraints, it was not always possible to run both controlled and uncontrolled tests at the same site in a plant. Furthermore, it was often necessary to determine normalized values in order to obtain meaningful comparisons even between tests at the same site. This was true simply because the vehicle mix and average speed on test roads varied from day to day. Therefore, the measured emission factor values had to be normalized in order that a change in vehicle mix or speed was not mistakenly interpreted as a change in control efficiency for the technique being tested.

The method used in this study to normalize measured emission factors was based on MRI's experimentally determined predictive emission factor equation for emissions from vehicles traveling on unpaved roads.[4] Basically, average vehicle weight, number of wheels, and speed during a test were compared to a standard set of values and the comparison used to normalize the measurement-based emission factors.

The control efficiency in percent (C) is found as

$$C = 1 - \frac{\bar{e}_c}{\bar{e}_u} \times 100\%$$

where

$\bar{e}_c$ = geometric mean of normalized emission factors for controlled roads

$\bar{e}_u$ = geometric mean of normalized emission factors for uncontrolled roads

EPA Form 2350-4 (4-80)
(PREVIOUSLY CIN. EPA FORM 287)
TYPING GUIDE SHEET

FINAL TEST RESULTS FOR INITIAL STUDY

The results of the initial study in regard to the control of particulate from unpaved roads are shown in Figures 1 and 2. Figure 1 portrays the decay in the control efficiency of watering at an application intensity of 0.59 liters/m^2 (0.13 gal/yard^2) for total particulate (TP), inhalable particulate (IP)--particles less than 15 μm in aerodynamic diameter, and fine particulate (FP)--particles less than 2.5 μm in aerodynamic diameter. As can be seen, the control efficiency decayed to a range of 50 to 61% for all particle sizes within only 4.4 hr after application. Approximately 78 trucks of 50 tons average weight used the road hourly. The decay rate could have been much more rapid were it an 85°F day in July rather than a 60°F day in November. The decay rate for water is also sensitive to both time and to the number, type, and speed of vehicle passes.

Figure 2 portrays the decay in control efficiency of a petroleum resin at an application intensity of 0.86 liters/m^2 (0.19 gal/yard^2) of 17% solution in water for TP, IP, and FP. A captive passenger van and pick-up truck were used to obtain an average of 50 vehicle passes per hour during daylight hours on an otherwise untraveled road. The control efficiency decayed to a range of 90 to 95% for all particle sizes after approximately 1,200 vehicle passes which occurred in 2 calendar days at the test site. At a site with only natural plant traffic, 1,200 vehicle passes could occur anywhere in a range of 1 to 20 calendar days.

CONCLUSIONS FROM INITIAL STUDY

Conclusions were gleaned from the initial study in the following areas: (1) quantification of control efficiency decay; and (2) improvements to the study design.

CONTROL EFFICIENCY DECAY

1. A decay in the control efficiency of water applied at an intensity of 0.59 liters/m^2 (0.13 gal/yard^2) was measured for heavy-duty traffic on unpaved roads. The control efficiency for watering at the above application intensity, 4.4 hr after application, was 55.0% for TP, 49.6% for IP, and 61.1% for FP. The control efficiency of watering at the above application intensity was above 95% for all particle sizes 1/2 hr after application.

2. A decay in the control efficiency of a 17% solution of a petroleum resin applied at an intensity of 0.86 liters/m^2 (0.19 gal/yard^2) was measured for light-duty traffic on unpaved roads. The control efficiency of the resin at the above application intensity, 25 hr after application, was 99.5% for TP, 98.6% for IP, and 97.4% for FP. However, this road had been closed to traffic for most of the 25 hr to allow curing. Fifty-one hours after application, these efficiencies had decayed to 93.7% for TP, 91.4% for IP, and 93.7% for FP.

EPA Form 2350-4 (4-80)
(PREVIOUSLY CIN. EPA FORM 337)
TYPING GUIDE SHEET

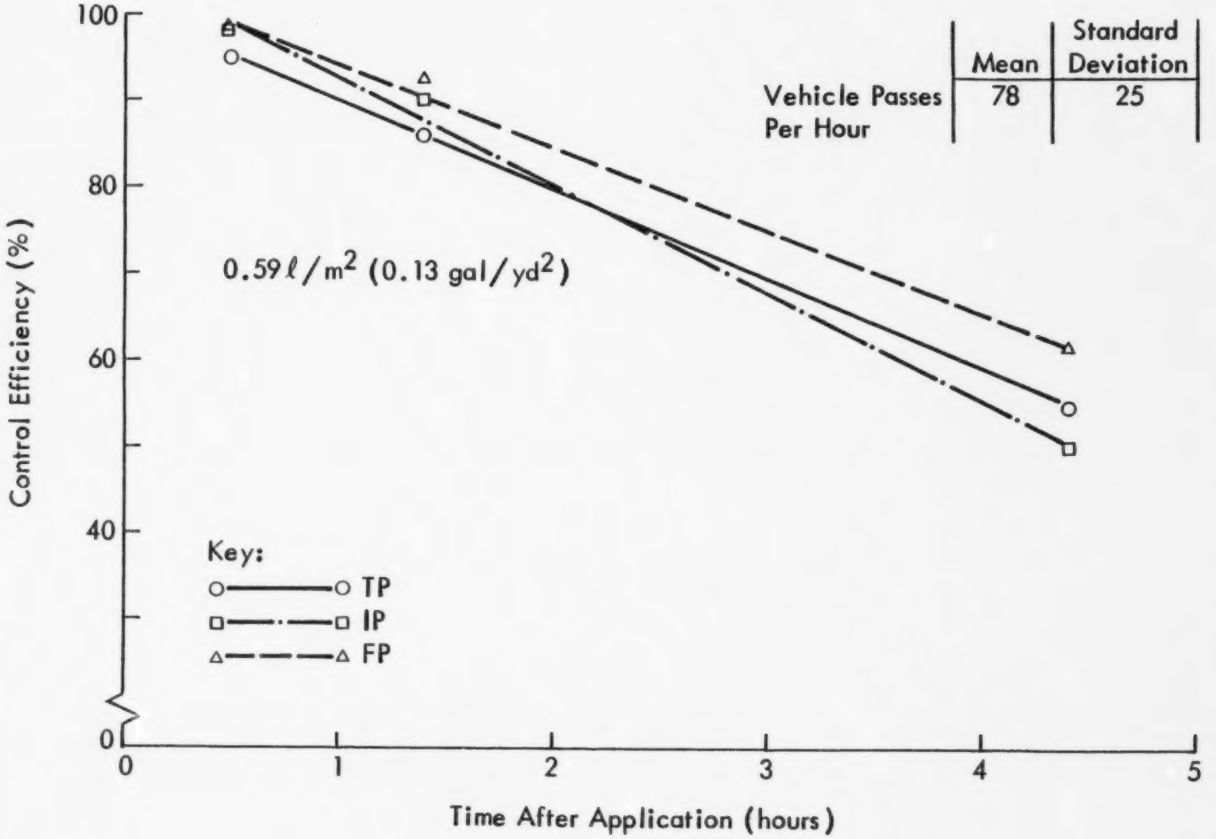


Figure 1. Decay in control efficiency of watering an unpaved road under heavy-duty traffic.

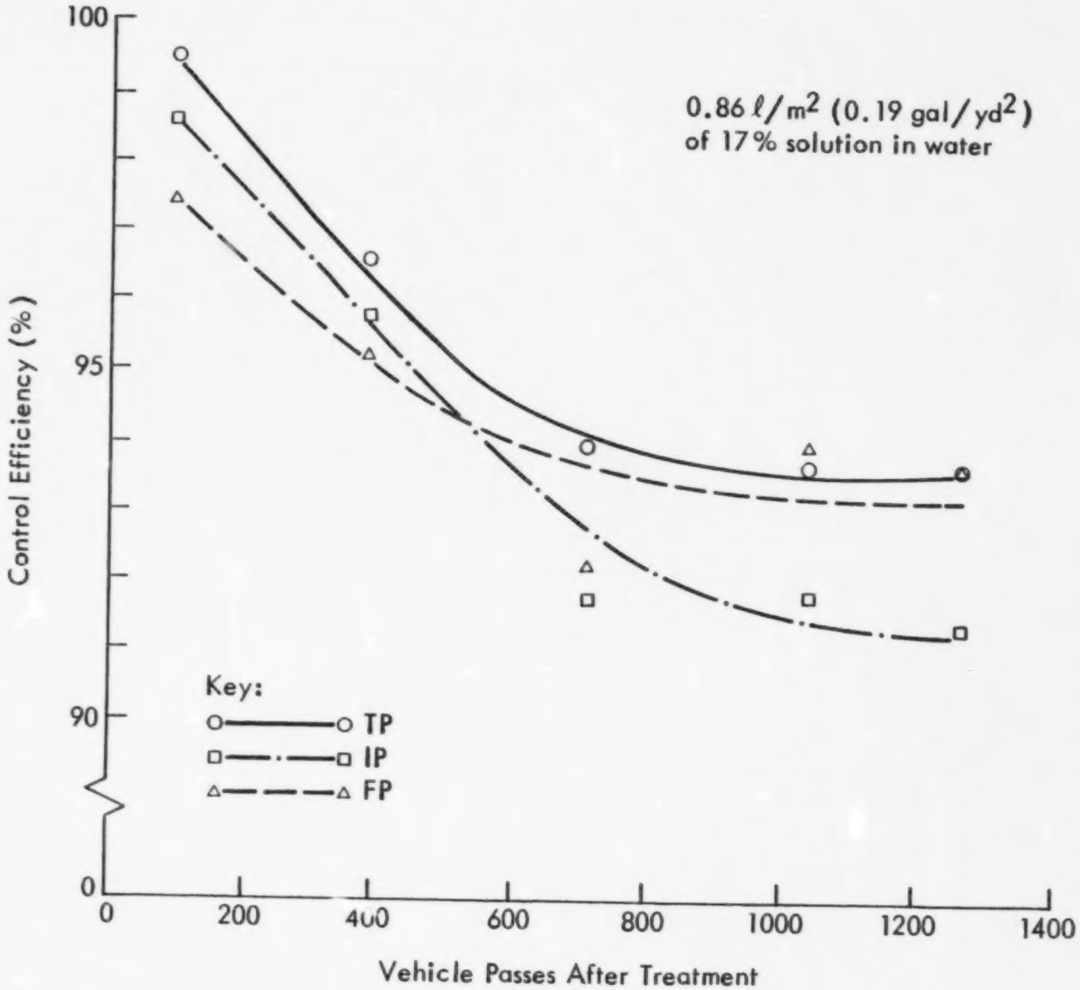


Figure 2. Decay in control efficiency of a petroleum resin applied to a light-duty unpaved road as a function of vehicular passes.

3. A decay in control efficiency with time after application was measured for most control techniques tested. This means that a reported efficiency value has meaning only when given in conjunction with a time after a specified application. If available, it is even more desirable to know the number of vehicle passes after application.

IMPROVED STUDY DESIGN

1. Application intensity should be measured during the actual application of the chemical suppressant. It is far too difficult to attempt to estimate the application intensity from plant records or from calculations involving estimates of applicator speed, road width, width of spray, and time to empty a tank of given size.

2. Since the decay in control efficiency is related not only to time, but also to the number of vehicle passes, traffic counts must be taken not only during testing but also during the periods between tests; thus, automatic traffic counters must be deployed on site.

3. When attempting to quantify IP and FP control efficiencies, it is important to measure IP and FP concentrations both upwind and downwind, since downwind concentrations are not much larger than upwind for highly controlled unpaved roads.

TEST METHODOLOGY FOR THE FOLLOW-ON STUDY

Because the current testing program is an outgrowth of the initial study, the basic methodology remains unchanged. However, a number of revisions have been made to better characterize the control efficiency decay over a long period after application. These improvements fall into the three categories of particle sizing, control application measurement, and definition of the decay function for control efficiency. The remainder of this section describes these revisions in methodology.

Provision was made to measure the upwind particle size distribution using a cyclone/impactor combination. Experience has shown that a knowledge of the background size distribution is essential in determining control efficiencies for IP and FP emissions. This is due to the fact that the IP and FP concentrations measured near a controlled unpaved road are often not more than two or three times the upwind concentration at an industrial site. Thus, size-specific background concentrations are required in order to accurately determine control efficiency values for particulate emissions in the smaller size ranges. Arrangements have also been made to determine whether the upwind particle size distribution varies with height. Finally, in order to account for the gravitational settling of large particles, small 37 mm cassette samplers are being deployed at the same locations as the cyclone/impactors. Microscopic analyses of the filters are being performed to determine the largest particle diameter which is important in developing particle size distributions at the coarse particle end.

Because the efficiency associated with a control measure is only directly applicable to a particular dilution ratio and application intensity, arrangements have been made to better quantify these variables. By either working closely with plant personnel or actually contracting the work, MRI has been able to directly oversee the mixing and application of the solution. The intensity of application is being measured by placing tared sampling pans at numerous locations on the road surface prior to application. Individual intensity measurements are being examined to determine any significant spatial variations and to obtain an average value.

The decay in control efficiency is heavily dependent upon the number of vehicle passes after application. In order to define decay as a function of traffic volume as well as time, pneumatic tube axle counters are being deployed at the site immediately after application. In addition to vehicle counts during testing, independent counts determining the distribution of vehicles by number of axles are being taken during each shift at the plant. This information is being used to convert axle counts into the number of vehicle passes.

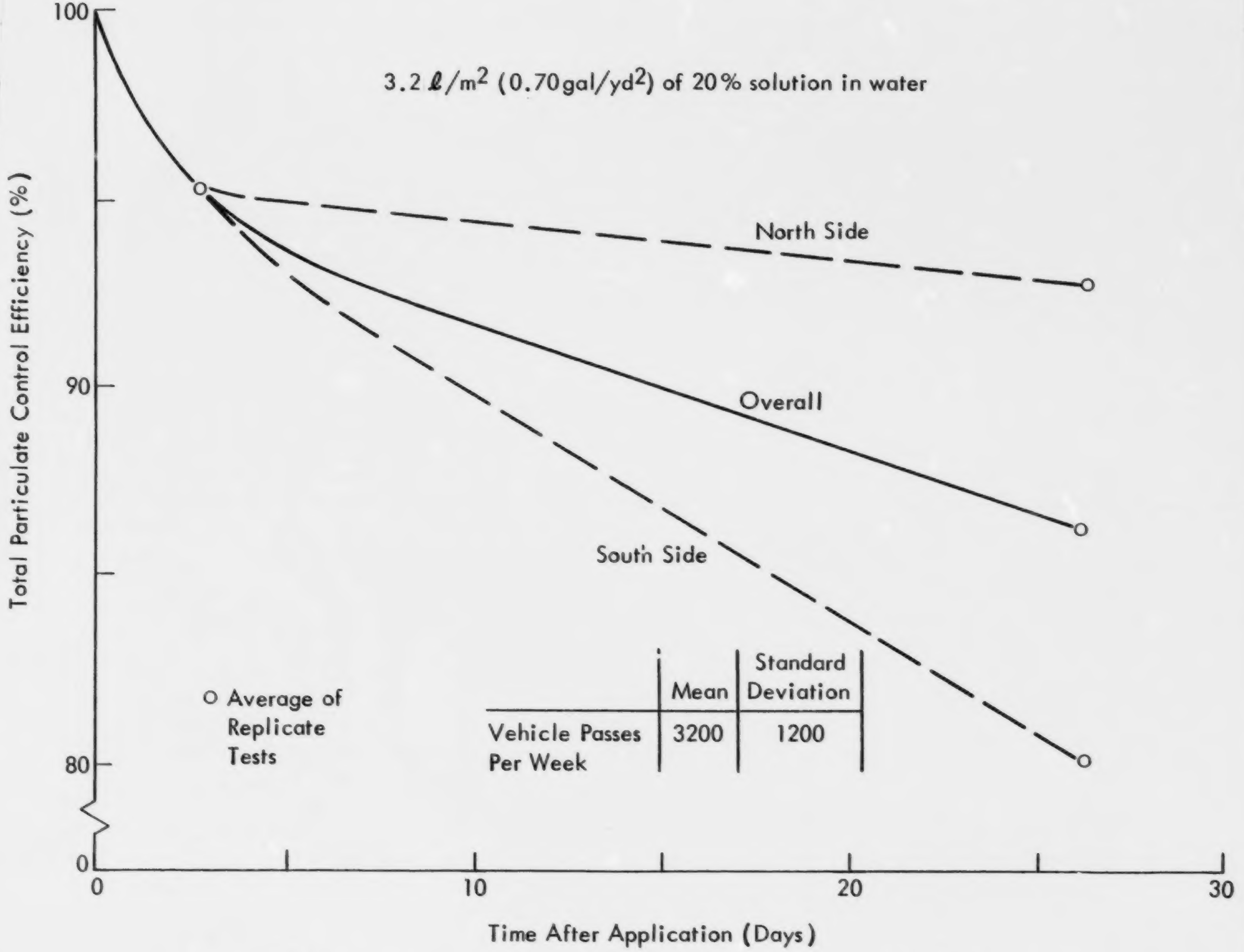
Finally, the difference in the measurement-based emission factor when using a 10 m (33 ft) exposure profiling tower instead of a 6 m (20 ft) tower is being assessed.

PRELIMINARY RESULTS FROM THE FOLLOW-ON STUDY

Preliminary results from the current testing program are presented in Figures 3 and 4. Figure 3 depicts the decay in TP control efficiency associated with an emulsified asphalt applied to a wide, unpaved slag haul road at an iron and steel plant. The control was applied as a 20% solution at an average intensity of 3.2 liters/m^2 (0.70 gal/$yard^2$). Figure 4 depicts the decay in TP, IP and FP control efficiency of water on another unpaved slag haul road.

It should be noted that separate curves are shown in Figure 3 for the north and south portions of the road. At the onset of testing 26 days after application, it was found that the north and south portions of the road exhibited different rates of control efficiency decay. This is probably due to the queuing of 18-wheel trucks on the south half of the road to use the weigh station. When there are several trucks waiting in the line at the scale, the south side of the road is subjected to stop and go traffic. It is believed that the larger friction forces associated with braking and accelerating cause the much more rapid decay of control observed on the south side of the road.

Because of the the different rates of control efficiency decay, the overall emission factor was apportioned over the two sides of the road. The apportionment procedure is based on MRI's predictive emission factor equation and silt contents measured on both sides of the road. The apportioned emission factors were then normalized and control efficiencies were calculated for each side. It is of interest to note that the south side had a greater rate of decay than the north side, even though its application intensity was 65% greater than the north side.

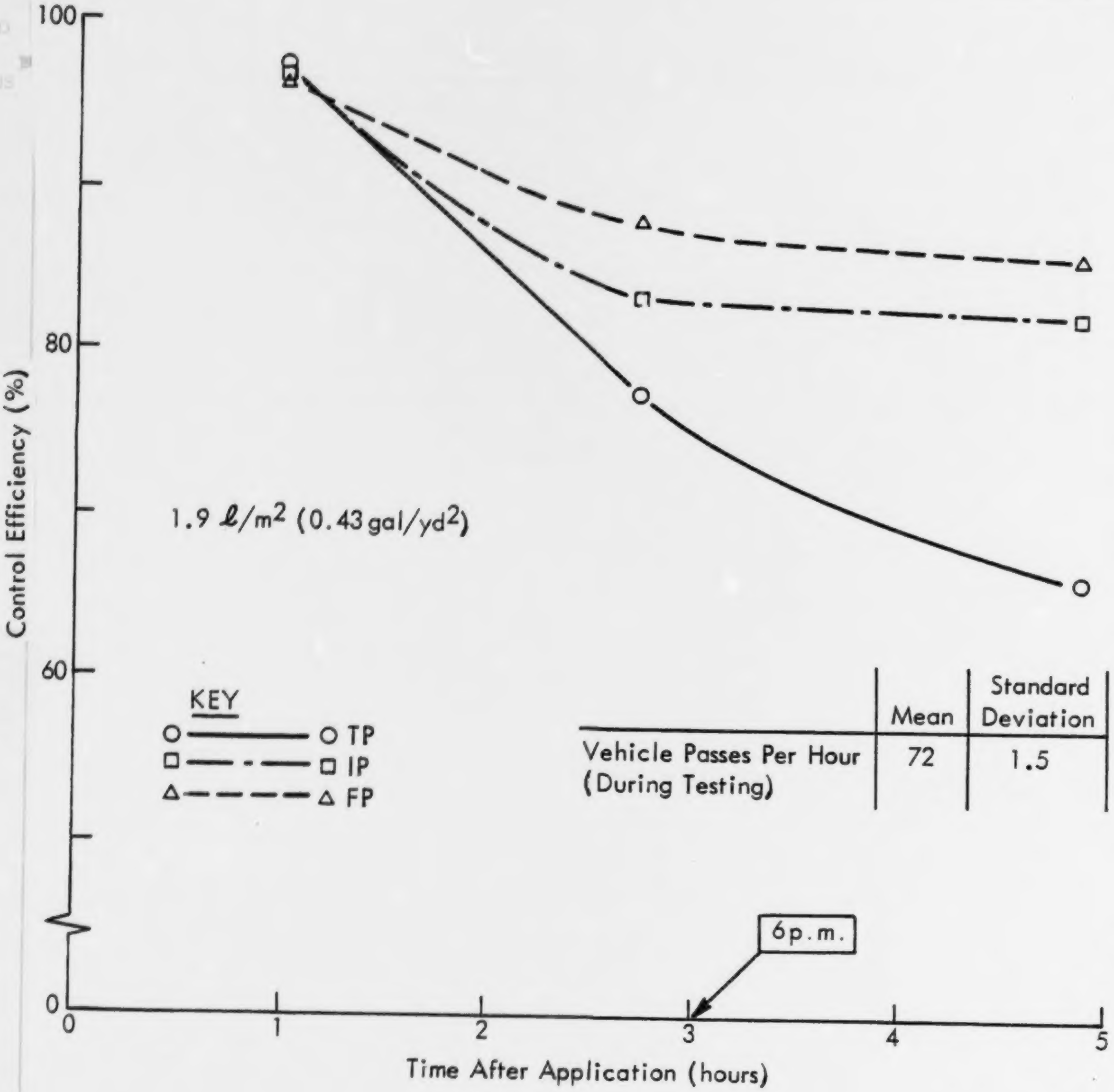


	Mean	Standard Deviation
Vehicle Passes Per Week	3200	1200

Figure 3. Preliminary control efficiency decay of an emulsified asphalt.

EPA Form 2350-4 (4-80)
(PREVIOUSLY CIN. EPA FORM 327)
TYPING GUIDE SHEET

BEGIN FIRST LINE OF TEXT HERE
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD; BEGIN SECTIONS HERE



	Mean	Standard Deviation
Vehicle Passes Per Hour (During Testing)	72	1.5

Figure 4. Preliminary control efficiency decay of watering an unpaved road under heavy-duty traffic.

BEGIN LAST LINE OF TEXT
EPA Form 2350-4 (4-80)
TYPING GUIDE SHEET

Figure 4 presents preliminary control efficiency values associated with watering of unpaved roads at a measured application intensity of 1.9 liters/m^2 (0.43 gal/$yard^2$). It should be noted that controlled testing began fairly late in the day because of logistical problems. As a result, testing continued past dusk. The ambient air temperature at the start of testing was 35°C (95°F) and 26°C (79°F) at the conclusion of testing.

Comparison of Figures 1 and 4 shows that the initial rates of decay are approximately the same for watering at two different plants, despite the differences in ambient temperature and application intensity. However, as seen in Figure 4, the rate of decay between 2 and 4 hr in IP and FP control efficiency was minimal. Undoubtedly, this is due to the greatly reduced insolation as the angle of the sun decreases in the early evening.

PRELIMINARY CONCLUSIONS FROM THE FOLLOW-ON STUDY

The following preliminary conclusions are based on the results of the follow-on study presented above.

1. There appears to be a more than linear increase in control efficiency with increases in chemical control dilution ratio and application intensity. The areas surrounding the emulsified asphalt test site were treated with the same chemical; however, the solution was twice as dilute and was applied at roughly half the intensity. These surrounding areas required reapplication approximately every third day. However, the test site itself still showed control efficiencies on the order of 90% one month after treatment.

2. Higher rates of control efficiency decay are associated with the increased shear stresses caused by stop-and-go traffic. Attempts to modify existing traffic patterns where possible would have the effect of extending a chemical control's lifetime. This would reduce the cost of an unpaved road dust control program.

3. A dust control program based on watering of unpaved roads could entail provision for seasonal variations and reduced evaporation during hours late in the day. The rate of control efficiency decay was found to be very similar on a hot day to that measured on a road treated at one-third the intensity on a cool day. Furthermore, the control of smaller-size particulate emissions remains much more constant as the amount of insolation decreases. Consideration of daily and seasonal variations could result in an equally effective watering dust control program at less cost. However, additional field measurements under a variety of meteorological conditions are required.

4. Finally, as a check on MRI's sampling methodology, a 10 m (33 ft) profiling tower was operated 5 m from the test road. The emission factors calculated using both a 6 m (20 ft) and the 10 m profiling arrays were found to differ by less than 10%. Thus, when isokinetically sampling the total particulate plume close to the source, a 6 m profiling array is more than adequate.

ACKNOWLEDGMENT

This work was performed under U.S. EPA Contract No. 68-02-3177, Tasks 4 and 14 (project officers: Mr. Robert McCrillis and Mr. Robert Hendriks).

REFERENCES

1. Cuscino, Thomas, Jr., Gregory E. Muleski, and Chatten Cowherd, Jr. Iron and Steel Plant Open Source Fugitive Emission Control Evaluation. Final Report, EPA Contract No. 68-02-3177, Task 4, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, August 31, 1982.

2. Small, Mark, Russel Bohn, and Chatten Cowherd, Jr. Measurement of Open Dust Inhalable Particulate Emission Factors at an Integrated Iron and Steel Plant. Paper presented at the APCA Specialty Conference on: Air Pollution Control in the Iron and Steel Industry, held at the Hyatt Regency Hotel in Chicago, Illinois, April 21-23, 1981.

3. Cowherd, Chatten, Jr., Thomas A. Cuscino, Jr., and Mark Small. Cost Effectiveness of Road Dust Controls. Paper presented at the U.S. EPA Symposium on Iron and Steel Pollution Abatement Technology for 1981, held at the McCormick Inn in Chicago, Illinois, October 6-8, 1981.

4. Cowherd, Chatten, Jr., Russel Bohn, and Thomas Cuscino, Jr. Iron and Steel Plant Open Source Fugitive Emission Evaluation. EPA-600/2-79-103, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, May 1979.

EPA Form 2350-4 (4-80)
(PREVIOUSLY CIN. EPA FORM 337)

TYPING GUIDE SHEET

The work described in this paper was not funded by the U.S. Environmental Protection Agency. The contents do not necessarily reflect the views of the Agency and no offical endorsement should be inferred.

THE EFFECT OF DUST CONTROL MEASURES IN A DUTCH IRON AND STEEL WORKS

by: Cornelis A. Aronds
Environmental Control
Hoogovens IJmuiden
P.O. Box 10000, 1970 CA IJmuiden
Netherlands

ABSTRACT

At the expense of large investments and exploitation costs Hoogovens has achieved a considerable reduction of its dust emission from process sources. A measuring network was installed around the works to assess the effect of this reduction on the quality of the ambient air. Instruments according to the US EPA high volume sampler (HVS) method and the directives of the West German "Landesanstalt für Immissionsschutz (LIB)" were used in parallel for comparison of the results.

Notwithstanding the reduction in the emission no significant decrease in particulate concentrations could be found. After correction for the large influence of several weather factors and the contribution of other sources a better agreement with expectations could be obtained, especially with the German method. One of the reasons is that the German method is less sensitive to coarse dust in the air, meaning it is independent of the wind speed. Moreover, this method has some other advantages.

INTRODUCTION

As with many iron and steel companies in the world, Hoogovens IJmuiden in the Netherlands has spent much effort for a considerable period of time to adapt its plant to the modern demands concerning the protection of the environment. Since the construction of the oxygen steel plant no. 1 in 1956 the removal of dust from waste gases became normal practice at IJmuiden, but the increasing pressure from new legislation compelled Hoogovens to extend the field of these activities on a much broader scale. Up to 1973 about 50 million Dutch guilders were spent on dust arrestment facilities, whereas in the last ten years these costs were about doubled.

From the middle of the seventies the production at IJmuiden has been perforcely kept at a level of 5 to 5.5 million tons* of crude steel with only minor facility alterations. At that time some 13000 tons of dust were emitted annually from process sources. Additional control measures since that time resulted in a considerable reduction of the dust emission, leading to a level of 7100 tons in 1982, i.e., 54 percent of the amount in 1974.

---

* metric tons are used throughout this paper

Table 1 gives a summary of the measures taken and an indication of the emission reduction.

Naturally the question arose whether this drop in emission had resulted in lower dust concentrations in the air, especially in the inhabitated areas around the works. The local authorities had already started measurements of the TSP according the EPA method. From these data it was difficult to see a significant change in concentration as shown in figure 1.

Hoogovens therefore decided to investigate the problem by herself, building her own monitoring network in order to study methods and results in an extensive way. She also took the opportunity to introduce another, German, method to have the possibility to compare the results with the American one.

This paper gives a description of this investigation with the conclusions reached sofar.

INVESTIGATION

The purpose of the investigation was twofold: on the one hand we had doubts about the accuracy of the HVS method as applied in our situation. On the other hand we wanted also to find out why so little progress was found in the improvement of the conditions around the works in terms of TSP. As it is Hoogovens policy to reduce emissions as far as technically and economically feasible, it was (and is) difficult to accept that no relationship seemed to exist between the many efforts taken and the quality of the air. Therefore we worked along several lines:

- looking into the EPA method concerning its reproducibility, the sampling and laboratory procedures,
- comparing the EPA method with the German LIB method,
- interpretation of the data in close connection with weather statistics,
- finding a way to calculate the "contribution" of the works in the annual mean TSP value to have a possibility to distinguish the impact of the works from the impact of other sources.

Concerning the last line it is appropriate to remark here that we limited our search to the data as obtained from the monitoring network as such, and that we did not apply other techniques such as special studies with tracer components. These techniques will probably be introduced in a later stage. Also we left out calculations based on mathematical models, finding them too unreliable for the complex situtation at hand. Modeling is an interesting topic for future discussions.

MONITORING NETWORK

Hoogovens IJmuiden is an integrated iron and steel works situated about 20 kilometers west of Amsterdam at the coast of the North Sea. It is near an important bulbgrowing area, a seaside resort (Wijk aan Zee) and the towns Beverwijk and IJmuiden. The climate is moderately mild with prevailing winds coming from the direction of the sea.

EPA Form 2350-4 (4-80)
(PREVIOUSLY CIN. EPA FORM 287)
TYPING GUIDE SHEET

TABLE 1. EMISSIONS OF DUST

Plant	Control measures	Emission (ton/year)		
		1974	1979	1981
Sinterplant	Dedusting exhaust air discharge end, elec. prec.	5000	2800	3100
Pelletizing plant	Gaswashing strand gases, elec. prec. ore mills	800	600	700
Coke ovens 1	Renovation batteries	1100	1100	600
Coke ovens 2	-	800	800	800
Hot metal casting mach.	-	30	30	10
Blastfurnace 3	Ending of production	300	70	-
Blastfurnace 4	Lower production, no measure	700	700	600
Blastfurnace 5	Lower production, no measure	600	600	-
Blastfurnace 6	Casthouse exhaust, dedusting baghouse	700	100	100
Blastfurnace 7	Idem	700	700	200
Oxygen steel plant 1	Primary and secundary fume exhaust dedusting in venturiscrubbers	900	500	200
Oxygen steel plant 2	Idem	700	700	500
Ingot foundry	Exhaust dedusting	100	30	30
Scrap yard F	-	300	400	200
Plate mill	Dedusting steelgritmachine, baghouse	200	100	-
Slabbing mill 1, 2, 3	Dedusting hot scarfing, wet scrubbers	150	50	50
Cold rolling plant 1, 2	-	20	20	10
Total		13100	9300	7100

EPA Form 2350-4 (4-80)
(PREVIOUSLY CIN. EPA FORM 281)
TYPING GUIDE SHEET

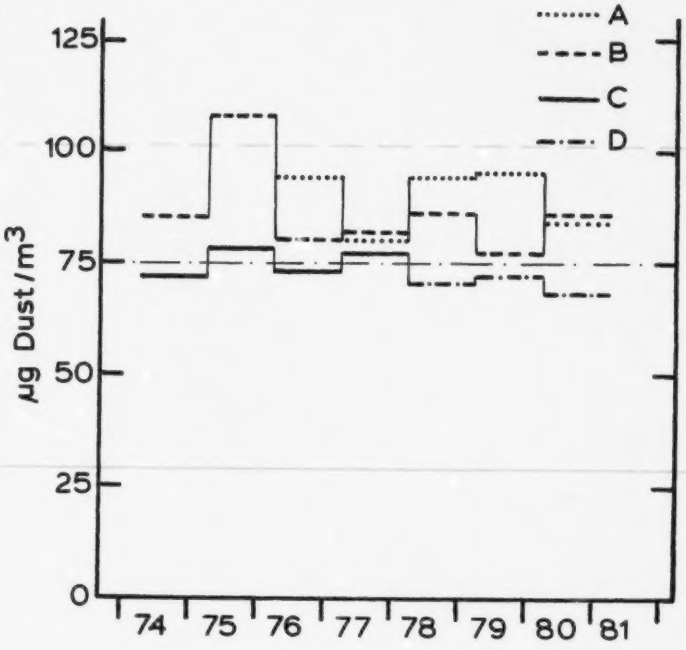


Figure 1. TSP_levels (HVS)

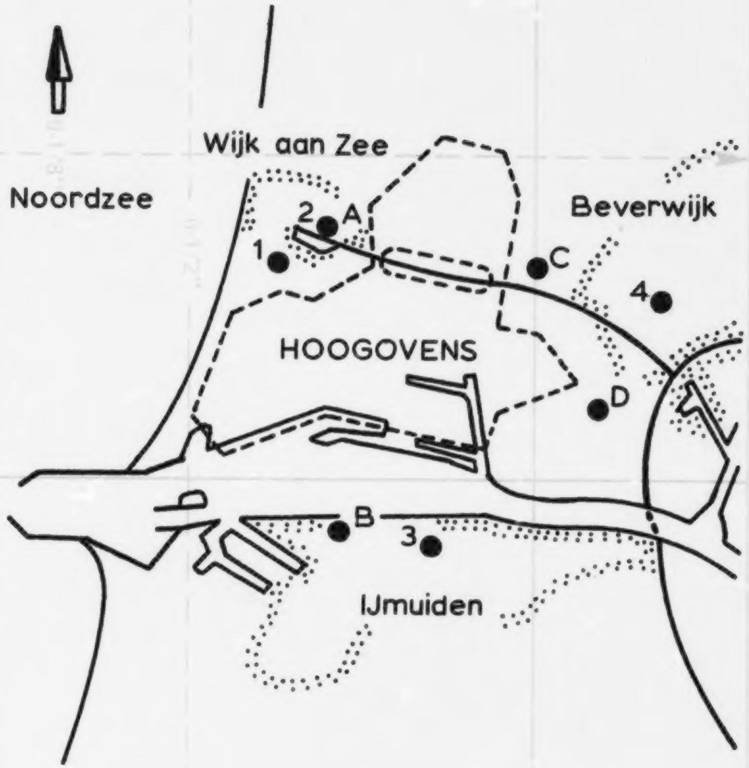

Wijk aan Zee
Noordzee
Beverwijk
HOOGOVENS
IJmuiden
1
2
3
4
A
B
C
D

Figure 2. Monitoringnetwork
Hoogovens: 1 to 4.
Prov. authority: A to D.

The monitoring sites were chosen in such a manner that they could be considered as representative for the domestic area around the works (see also figure 2). One reference station was placed near Amsterdam, about 20 kilometers southeast from the works, to have an impression of the particulate level in a suburban area remote from industry.

Each station was furnished with an EPA High Volume Sampler and a LIB sampler (developed by the German Landesanstalt für Immissionsschutz, Nordrheinland-Westfalen). On one site, no. 2, an extra HVS was placed to study the effect of passive loading, occuring when filters are left in the sampler house outside the sampling period. At site no. 2, samples were taken in duplicate.

PROCEDURES

All sampling and laboratory procedures were performed according to the official documents:

- the American reference method as described in the Federal Register (vol. 36, no. 84, part II, p. 8191 - 8194, Appendix B), the HVS method,
- the German reference method as described in the V.D.I. directive 2463, Blatt 4, the LIB method.

At the start of the investigation in 1979 the new text of the High Volume Method published in the Federal Register vol. 47, January 1982 was not available. Some new elements mentioned therein (paragraph 6.6. and 6.7) however were already introduced in our protocol.

The LIB method is characterized by an air sample volume of about 400 m^3 per 24 hours, drawn upwards through a cylinder with a length of 20 cm and a bore of 10 cm, used as a size selective inlet. The air then passes a circular glass fiber filter (coded GF 9) with an effective surface of 78.5 sq. cm. The weight increase of the preweighted filter divided by the air volume registered in a calibrated gasmeter, corrected for the temperature, gives the average particulate concentration. The apparatus is officially registered in the German law.

Air samples were normally taken on working days. For one year only, samples were also taken on Saturday and Sunday. The number of samples per site per year was about 200, enough to keep the variance of the annual mean between acceptable limits. For one year (1979) an independent research institute* checked the network and the laboratory procedures for correct performance. This institute certified that all procedures were carried out in accordance with the documents mentioned above.

From the individual data obtained annual averages were calculated and compared with the official air quality limits. The daily values of TSP were also linked with meteorological parameters as: wind direction and speed, and rainfall. The special treatment of the data to estimate the "works contribution" will be dealt with in a later paragraph.

---

* Research Institute for Environmental Hygiene TNO

BEGIN FIRST LINE OF TEXT HERE
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD, BEGIN SECTIONS HERE

RESULTS

Methods

In 1979 we tested on site no. 2 with two collocated HV samplers the reproducibility of the method under the local conditions. It was found that the difference between the geometric means of the two samplers was on average not more than 1 %, which is good. This result could be obtained by carefully checking each step of the procedure, especially the calibration of the sampled volume of air per 24 hours.

The test with the filters exposed to the atmosphere without drawing of air through them, to establish the effect of passive loading, showed a difference of means of about 14 %, with 22 pairs, a significant result (the chance of occurrence by accident smaller than 5 %). This difference is large as a consequence of the relative long time of exposure, in our case 5 days, normal for a sampling scheme of one filter in 6 days. Based on this experience we applied systematically the rule that each filter should not be installed before starting the sampling period and should be retrieved immediately after the ending of this period. This procedure is also recommended in the new version of the HVS method.

A comparison between the HVS and LIB method shows that there seems to be a reasonably good agreement between them. Table 2 summarizes the correlation coefficients per site and the data about the regression lines (linear) relating HVS values with LIB values, for 1979.

There is however an influence of the wind speed on the ratio HVS/LIB value. With increasing speed this ratio becomes larger, for the sites close to the works up to values of 1.5 (see figure 3). At the site in Amsterdam we found a decrease of the ratio with increasing wind speed. The explanation of this phenomenon is in our opinion that the HVS samples more dust of the coarse fraction with increasing wind speed than the LIB, and that more close to the works, especially in the sandy surroundings near the coast, more coarse dust is offered to the samplers than in a more urban area. This greater sensitivity of the HVS for wind influence is considered by us as a great disadvantage of this method. The application of a size selective inlet will certainly be a step forward.

Daily measurements

The figures 4 and 5 represent the measuring results of the two methods, expressed as a moving average (annual means) from January 1980 till January 1982. One can see clearly the striking drop of the values for all sites, apparently due to the influence of control measures within our works. This drop is observed for both methods. However, it is unlikely that the monitoring station in Amsterdam is under the influence of our works. Therefore the drastic reduction of the TSP level must be attributed to other causes, the most probable one being the influence of weather. Nevertheless, our interest still lies in the answer to the question whether the control measures had any detectable influence on the TSP lever or not. This is specially important where the TSP levels on the more closely situated

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
EPA Form 2350-4 (1-80)
(PREVIOUSLY CIN. EPA FORM 287)
TYPING GUIDE SHEET

TABLE 2. DATA RELATION HVS - LIB

Function	Site	Sample size n	Correl. coeff. r	Stand. deviation s	Regression coefficient a	b
y=ax	1	231	0.9843	20.2	0.963	-
	2	232	0.9810	21.4	0.973	-
	3	228	0.9890	12.7	1.001	-
	4	224	0.9869	14.7	1.023	-
	5	231	0.9816	15.6	1.104	-
y=ax+b	1	231	0.9455	-	0.943	2.753
	2	232	0.9312	-	0.928	5.812
	3	228	0.9452	-	0.978	2.154
	4	224	0.9469	-	0.990	3.304
	5	231	0.9244	-	1.009	7.921

Note: s = stand. deviation of differences between individual observations and the regression line
y = LIB
x = HVS

BEGIN FIRST LINE OF TEXT HERE
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD; BEGIN SECTIONS HERE

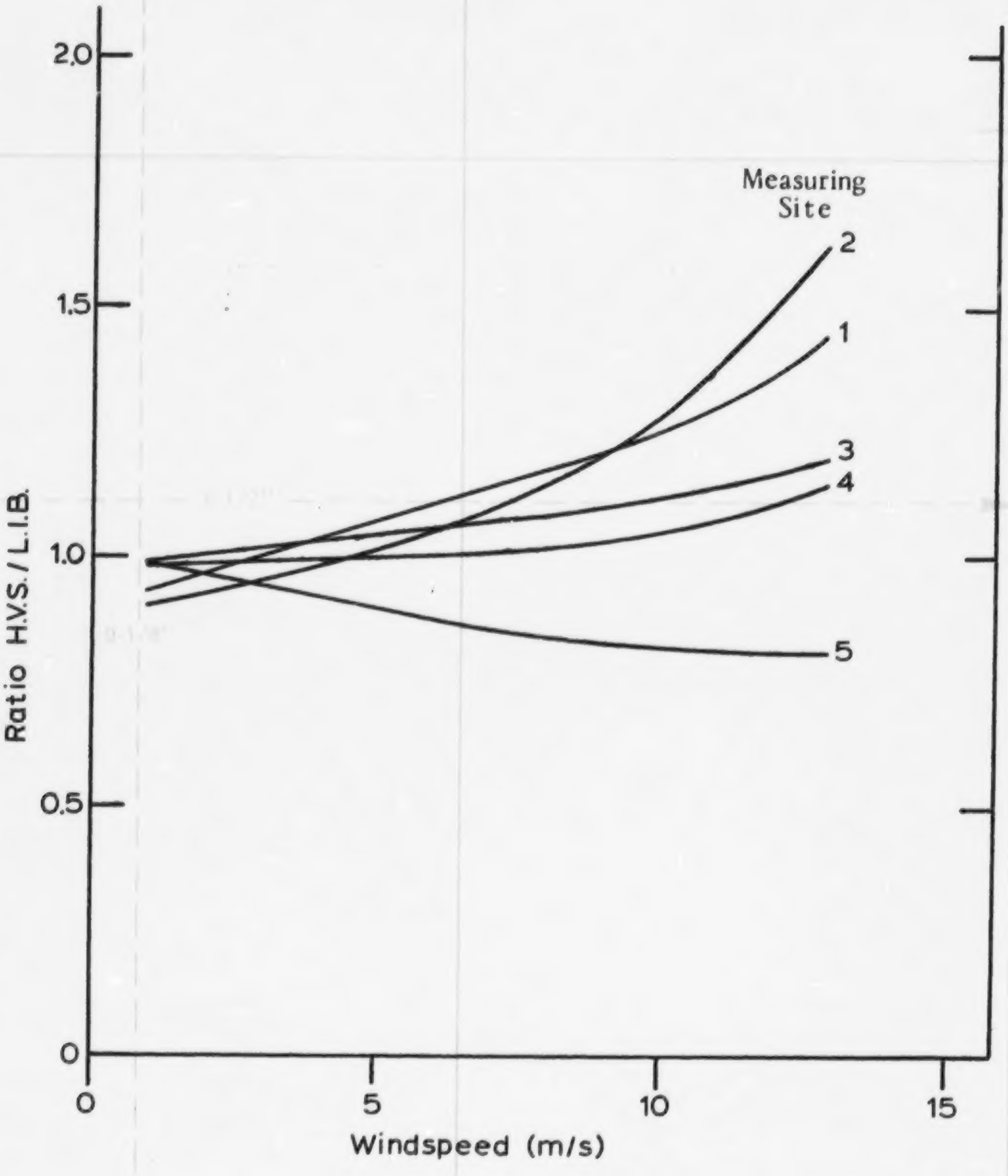


Figure 3. Influence windspeed on ratio HVS/LIB.

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA

PAGE NUMBER
EPA Form 2390-4 (4-80)
TYPING GUIDE SHEET

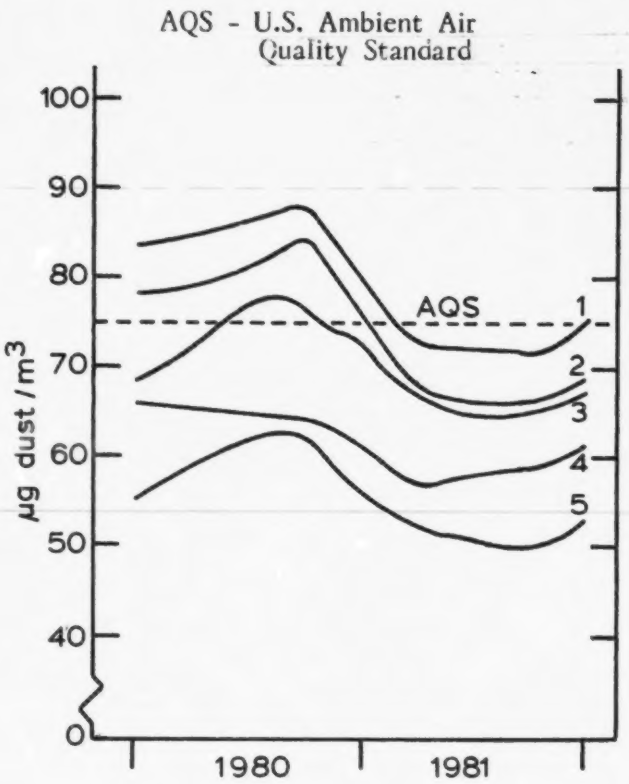


Figure 4. Moving annual geometric mean (HVS).

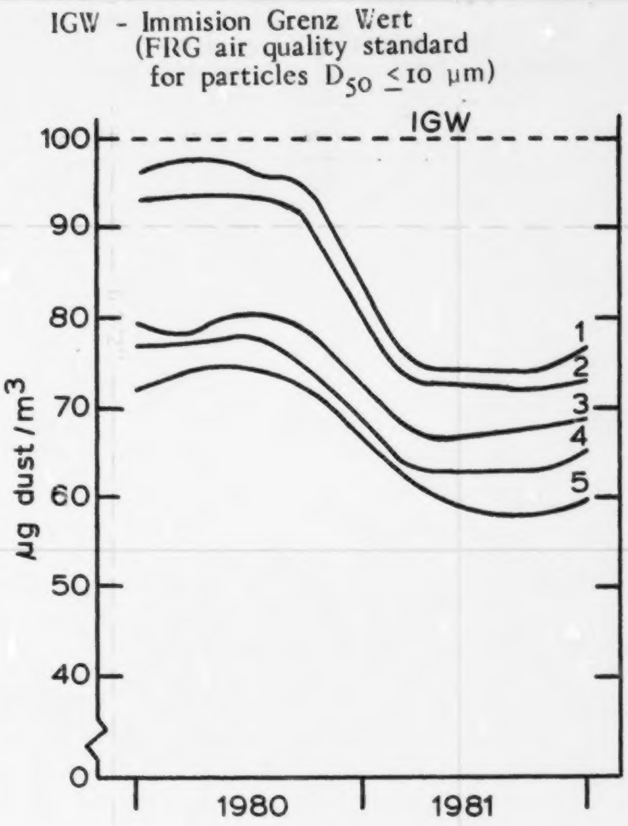


Figure 5. Moving annual arithmetic mean (LIB).

places were above the American standard of 75 micrograms/m^3. Large variations caused by changing weather conditions even from year to year make it very difficult to keep the TSP level under the required standard.

Judged by the German system, requiring a total dust concentation (annual aritmetic mean) under 200 microgram/m^3, measured by the LIB method, our situation is not critical in this respect, as the large fluctuations are well under the official German limit. It is striking that the two systems of monitoring for air quality standards are not compatible with each other and give different judgements of the same situation. This leads to the interesting question- which is the correct one?

As a last remark on this aspect it is good to be conscious of the fact that an annual mean value, constructed from observations on less than 365 days, will contain an experimental error depending on the number of observations per year. In our situation the inaccuracy of the annual geometric mean of TSP values is less than 5 %, based on about 230 days and calculated by the method of Hale (W.E. Hale, Atmospheric Environment 6: 419 - 422 (1972)). With smaller numbers of days, the inaccuracy increases drastically. For instance for a number of 110 days per year the inaccuracy is already 10 %, for 60 days 15 % of the annual geometric mean, reason to be very carefull with sampling schemes with a limited number of observations per year. With a strict interpretation of the limit, one would have to stay under this limit to an amount equal to the inaccuracy of the measured annual mean. This of course would cost extra money for investments recognizing the fact that the influence of control measures on the TSP level is not very large, as shall be explained in the next paragraphs.

CALCULATION OF THE WORKS CONTRIBUTION

Our goal is to separate the influence of the weather from that of the dust sources, and to discriminate the influence of different sources on the TSP level. As remarked under the paragraph "Procedures", we considered a few meteorological parameters important as a first approximation: wind direction, wind speed and rainfall. Atmospheric stability would be only a secondary factor as on most days the average stability would be neutral, i.e., median turbulence, over 24 hours.

Further, at the moment, we are not interested in the contribution of each individual source, but more how much is coming from our works as a whole, compared with the total of all other sources. If we could establish the contribution of the latter, that is establish the value of the "background" under local conditions, the estimation of the contribution of the works is in principle possible.

Our first task was to split the total set of data into a number of groups per year and site:

- two groups containing the data obtained on days with wind blowing from the works to the site, and days with wind coming from another direction, 3/4

BEGIN FIRST LINE OF TEXT HERE
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD: BEGIN SECTIONS HERE

- subdivision of the two groups into subgroups by criteria: dry or wet days and average wind speed more or less than 6 m/s, the mean wind speed in our region.

For each subgroup the geometric mean was calculated. Table 3 gives the result with the number of individual TSP values per subgroup (frequency of days appearing in the subgroup), independent of the wind speed. The annual means, for 1979 and 1981, are also indicated. From this table it can already be seen that dust concentrations were lower on days with rain. Wind direction has as expected a large influence, simply by the impact of the works.

The next step is to estimate the "background". To get a complete set of data, in which all weather situations are represented, one cannot use the observations of a single station because then, there is always one sector directed to the works and therefore not suitable for this calculation. By using however the same sector but then using the data of a station laying on the opposite side of the works (the weather side) one may compose a set of data from two stations which is fairly complete, including the contribution of important sources remote from the works.

By this method we found reasonable values for the background, comparable with values to be expected in an urban area. These values subtracted from the TSP would give an approximate figure for the contribution of the works on that special place. Table 4 contains the results. One can easily see that the background is a predominant part of the total suspended material and that the contribution of the works is a relatively minor part. This would already explain the small effect of pollution control measures on the TSP levels.

The last but still important step is to compare the works contribution from one year to the other, to see whether this could be a better indicator for the effect of lower emissions. However it is necessary then to correct for the weather, which differs significantly from year to year. We applied a very simple model to make this correction, i.e. by using the frequency of occurrence of certain weather situations, as shown in table 3, of one year for computing the averages in the other year. Mathematically this can be written as follows:

$$\bar{X}_k = \text{antilog} \frac{\sum_{i=1}^{j} n_{i,k} \log \bar{x}_{i,k}}{\sum_{i=1}^{j} n_{i,k}} \qquad (1)$$

in which:
$\bar{X}$ = annual geometric mean ($\mu g/m^3$)
n = frequency of days
k = year number, 1 = 1979 and 2 = 1981
j = number of subgroups in the set data
$\bar{x}$ = geometric mean of a subgroup

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA: OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS

EPA Form 2360-4 (4-80)
(PREVIOUSLY 5YN. EPA FORM 111)
PAGE NUMBER
TYPING GUIDE SHEET

TABLE 3A. MEANS AND FREQUENCIES HVS ($\mu g/m^3$)

Site	Wind direction sector (compass)	Weather	1979		1981	
			$\bar{x}_1$	n_1	$\bar{x}_2$	n_2
1	240-360-60°	dry	57.6	26	55.9	44
		wet	68.5	42	58.7	54
	60-240°	dry	127.7	54	130.5	31
		wet	96.7	43	90.9	35
	285-360-40° *	dry	43.0	8	52.6	30
		wet	53.8	18	49.0	22
	0-360°	Annual geom. mean $\bar{X}_k$	89.4	165	74.0	164
3	285-360-40°	dry	85.4	8	81.2	23
		wet	92.2	17	76.8	29
	40-285°	dry	79.6	74	71.7	52
		wet	56.2	69	51.7	59
	60-240° *	dry	87.5	56	82.9	30
		wet	56.3	44	51.0	35
	0-360°	Annual geom. mean $\bar{X}_k$	70.2	168	65.7	163

* To replace the same sector of the other site to obtain background

EPA Form 2350-4 (4-80)
(PREVIOUSLY CIN. EPA FORM 247)
TYPING GUIDE SHEET

TABLE 3B. MEANS AND FREQUENCIES LIB ($\mu g/m^3$)

Site	Wind direction sector (compass)	Weather	1979		1981	
			$\bar{x}_1$	n_1	$\bar{x}_2$	n_2
1	240-360-60°	dry	65	27	52	45
		wet	72	40	52	54
	60-240°	dry	140	55	124	31
		wet	123	44	84	35
	285-360-40° *	dry	49	8	45	23
		wet	60	16	46	30
	0-360°	Annual arithm. mean $\bar{X}_k$	101	166	72	165
3	285-360-40°	dry	89	8	84	23
		wet	97	18	68	30
	40-285°	dry	87	75	76	53
		wet	63	69	49	59
	60-240° *	dry	94	57	87	31
		wet	65	44	51	35
	0-360°	Annual arithm. mean $\bar{X}_k$	78	170	66	165

* See table 3A

TABLE 4. CONTRIBUTION OF WORKS, TSP - HVS ($\mu g/m^3$)

Site		1979 Uncorrected $\bar{X}_1$	1979 Corrected $\bar{X}_1$*	1981 $\bar{X}_2$	Difference 1981 - 1979 Absolute	Difference 1981 - 1979 Relative (% of 1979)
	Total	89.4	80.2	74.0	- 6.2	
1	Background	68.2	66.2	59.9	- 6.3	
	Contribution works	-	14.0	14.1	0.1	0.7
	Total	70.3	73.0	65.7	- 7.3	
3	Background	63.9	60.8	55.6	- 5.2	
	Contribution works	-	12.2	10.1	- 2.1	- 17.2

* For weather of 1981, annual geometric means

TABLE 5. CONTRIBUTION OF WORKS, TSP - LIB ($\mu g/m^3$)

Site		1979 Uncorrected $\bar{X}_1$	1979 Corrected $\bar{X}_1$*	1981 $\bar{X}_2$	Difference 1981 - 1979 Absolute	Difference 1981 - 1979 Relative (% of 1979)
	Total	101.0	90.6	72.0	- 18.6	
1	Background	76.5	73.6	58.4	- 15.2	
	Contribution works	-	17.0	13.6	- 3.4	- 20.0
	Total	78.0	81.1	66.0	- 15.1	
3	Background	72.3	68.6	56.1	- 12.5	
	Contribution works	-	12.5	9.9	- 2.6	- 20.8

* For weather 1981, annual arithmetic means

For a certain year k in (1) will have the same value in all places. Correction of a year for the weather of another year would mean that (1) converts to:

$$\bar{X}_1^* = \text{antilog} \frac{\sum_{i=1}^{j} n_{i,2} \log \bar{x}_{i,1}}{\sum_{i=1}^{j} n_{i,2}} \qquad (2)$$

$\bar{X}_1^*$ is the annual mean 1979 "corrected for the weather" in 1981.

Comparing a corrected 1979 TSP mean with the mean of 1981 gives a true picture of the change, without any influence of wind speed, wind direction and rainfall. This procedure can be followed for the total and the background values. To obtain the corresponding figures for the LIB the arithmetical averages are calculated and handled in the same way, except that the quantities are linear and not logarithmic.

Table 4 summarizes the HVS results of the calculations with corrected TSP values for 1979, compared with the values for 1981. One can see that the contribution of the works in the two locations is similar and that in one location there is a clear drop in the contribution over the years 1979 - 1981. The absolute contribution is in the order of 10 to 14 microgram/m^3, or 17 % of the total value.

In the same way the original values of the LIB measurements are grouped in table 5, containing also the corrected ones. Here the absolute contribution is 10 to 17 microgram/m^3, which also averages 17 % of the total dust concentration.

It is interesting to see that the drop in the works contribution, as measured with the HVS method is 1 to 17 % over 1979 - 1981, the drop however measured with the LIB method is about 20 % over the same period. From table 1 it can be seen that the dust emission dropped from 9300 tons in 1979 to 7100 tons in 1981, that is 24 % less than the amount in 1979. One is inclined to suppose that the LIB method gives a better agreement with expectations than the HVS method. An explanation could be that the HVS, which samples more coarse dust, is therefore more sensitive to fugitive sources like stockyards, for which measures were already taken before 1979. More information seems to be needed to complete the picture in this respect.

DISCUSSION

It is good to review the results of the measurements and the calculations in the light of the purpose of the investigation, i.e. finding the reason way the TSP level has not become significantly lower as expected

EPA Form 2350-6 (4-80)
(PREVIOUSLY LIN. EPA FORM 22)
TYPING GUIDE SHEET

from the emission reduction in the works. We consider two factors to be important.

First it must be recognized that annual means, measured by the HVS method (and other ones), always have a random error in the order of 5 % or more, depending on the size of the sample, that is the number of days of sampling. The error may increase, if passive loading of the filters occur, especially with varying numbers of days of exposure. Differences in the performance of the procedure between laboratories also lead to experimental errors, increasing the uncertainty of the answers. One could ask the question whether the method should not be standardized more rigourously than it is now, because differences in interpretation of the present protocol permit subjective approaches in the way of performance with regrettable deviations in the measuring results.

As an example: in paragraph 6.7 of the new text in the Federal Register of 1982 it is recommended to "minimize errors caused by particulate matter deposited on the filter during periods when the sampler is inoperative". We think that it is an absolute necessity to avoid such errors. The word "recommended" leaves too much space for interpretation of the user of the method.

The second point is that, at least in our situation, the contribution of the works in the local TSP level is relatively small, so the changes in the contribution will also be small. These changes will also be masked by the large variation of the weather factors. It is, therefore, a compelling requirement to correct for the yearly changing of the weather.

A standing question is of course whether the HVS is an ideal instrument for measuring dust concentrations in ambient air. From windtunnel tests it is known that the HVS retains particles with a size smaller than 5 micrometer with an efficiency of 100%, but capture of coarser particles is much less efficent. High wind speed will also introduce errors by the anisokinetic sampling of coarse particles. The LIB apparatus is less susceptible to these factors by its better designed sampling head.

There are also other reasons to have a preference for the LIB type of apparatus. First, by its circular sampling head the measurement is independent of the wind direction. Second, coarse dust will not fall upon the filter, because the airstream is drawn upward. No dust is taken up during nonsampling periods. Third, the calibration of the gasmeter is much simpler and more accurate than the orifice system of the HVS.

In the light of the above considerations it is in our opinion open to question whether the HVS method is sufficiently accurate to detect small changes in the TSP level as occurred in our situation, or other ones. Especially in bubble concept cases, where the influence of individual sources on the total TSP impact is relatively small, normally under 1 microgram/m^3, the accuracy of the measured annual mean must be better than about 1 percent, which for the HVS is certainly not the case.

EPA Form 2350-4 (4-80)
(PREVIOUSLY CIN. EPA FORM 241)

TYPING GUIDE SHEET

CONCLUSIONS

1) The small influence of dust control measures at process sources in IJmuiden on TSP levels in the surrounding area is due to the relatively small contribution of the works therein (about 17 %). The effect is masked by the strong influence of weather conditions.

2) There is serious doubt about the accuracy of the HVS method obtainable in practice. The LIB method is less susceptible to weather influences and more accurate. Both methods seem to be well correlated with each other. Wind speed however has a bearing on the ratio between the results of the two methods.

3) Strict standardization can improve the reliability of the measuring results as needed in feasibility studies such as the relation between investments and effects.

ACKNOWLEDGEMENT

The author wishes to express his gratitude to dr. ir. C.P. Heijwegen for reading the manuscript and for his constructive remarks, and also to Messrs P.J. de Haas, H. Geersema and E.G. Hofstede for their extensive assistance in the practical work.

The work described in this paper was not funded by the U.S. Environmental Protection Agency. The contents do not necessarily reflect the views of the Agency and no official endorsement should be inferred.

FUGITIVE DUST EMISSIONS FROM ROADS IN IRON AND STEEL MILLS: COMPILATION OF RESULTS AND USE UNDER EPA'S EMISSION TRADING POLICY

by: L.L. Simmons, C.L. Norton and M.J. DeBiase
Energy & Environmental Management, Inc.
P.O. Box 71
Murrysville, PA 15668

ABSTRACT

An emissions trade of fugitive particulate matter from open-dust sources for process fugitives can be accomplished through a structured approach to quantification of the emission reduction credit. Emission factors for open-dust sources can be used as a first approximation of the emissions. However, field data have shown that the average measured emission factors differ by a multiple of 0.90 for paved roads and 4.44 for unpaved roads as compared to predicted values. An exposure profiler test is recommended to quantify the emissions under current and proposed controls as part of an emissions trading application.

This information will be useful to environmental control personnel at iron and steel mills and the regulatory agencies in providing a good first order estimate of total uncontrolled and controlled fugitive emissions from roads.

INTRODUCTION

The U.S. Environmental Protection Agency (EPA) promulgated a formal policy statement on December 11, 1979 entitled the Alternative Emission Reduction Option Policy.[1] This policy became known as the Bubble Policy because of the unique nature by which total emissions from a facility were treated. Iron and steel facilities made formal applications under the Bubble Policy seeking to reduce their pollution control requirements on process fugitives by substituting additional controls on open-dust in-plant sources. Most notable of these applications were the Middletown facility of Armco, and the Neville Island facility of Shenango Incorporated. Subsequent to these two applications, a revised Bubble policy was proposed by EPA on April 7, 1982.[2] In this revised policy, which became known as the Emissions Trading Policy, particulate matter trades that include open-dust sources are still treated as State Implementation Plans (SIP) revisions. Additional air quality dispersion modeling and validation requirements retained in the new policy result in open-dust emissions trades as more difficult to obtain compared to trades involving only point source emissions.

Emissions trading gives the manager of a facility the flexibility to manage pollution as other aspects of the facility are managed, in the most cost effective way. In order to obtain the SIP revision the following four key elements must be met:

- Surplus - that the reductions are indeed beyond those required by the applicable permit, or the SIP;
- Permanent - that the applicant will permanently maintain the reduced emission level;
- Enforceable - that the reduction is legally binding on the applicant; and
- Real - that the reduction is measurable and not just a "paper" savings.

This paper presents a procedure by which a feasibility study can be undertaken by an applicant to assess whether or not sufficient open-dust fugitive dust emissions exist for use under EPA's Emission Trading Policy. Results of studies on open-dust emissions by this investigator and others are presented to indicate expected values of emissions from paved and unpaved roads in iron and steel facilities.

DEVELOPING THE OPEN-DUST EMISSIONS

Emissions from process fugitive sources such as tapping emissions from a blast furnace or electric melt shop have been determined through pseudo-isokinetic sampling. Although not perfect, emission factors have been developed for process fugitive sources at iron and steel facilities.[3,4] Generally, an acceptable emissions factor can be determined by observing an applicant's process and comparing it to those where prior tests have been conducted. In the case of paved and unpaved roads the emission factors in common usage have not been accepted by the regulatory agencies for purposes of emissions trading.[5] However, they do provide a good tool for conducting a feasibility study.

The emission factor for vehicular traffic on unpaved roads is presented below:[4]

$$EF = 5.9 \left(\frac{5}{12} \right) \left(\frac{S}{30} \right) \left(\frac{W}{3} \right)^{0.7} \left(\frac{w}{4} \right)^{0.5} \left(\frac{d}{365} \right) \qquad (1)$$

where EF = emission factor (lb/veh-mile)
s = silt content of road surface (%)
S = average vehicle speed (MPH)
w = average number of wheels per vehicle
W = average vehicle weight (tons)
d = dry days per year

Similarly the emission factor for paved roads is:[4]

$$EF = 0.090\ I \left(\frac{4}{n} \right) \left(\frac{s}{10} \right) \left(\frac{L}{1000} \right) \left(\frac{W}{3} \right)^{0.7} \qquad (2)$$

where I = industrial road augmentation factor
n = number of travel lanes
L = total surface dust loading on traveled portion of road

Data from ten mills are presented in Table 1 from field studies of surface characteristics of roads. Silt content was found to average 12.7 percent for unpaved roads and 10.5 percent for paved roads. Surface loading on the traveled portion of the paved road was found to average 3,580 pounds per mile. A high degree of variability is noted in the data in Table 1 and is reflective of several factors; specifically:

- facilities of differing complexity listed in Table 1 such as foundaries, finishing operations and fully integrated mills
- differing operating and maintenance practices exist at each facility
- road surface, berms and surface drainage are different at each facility

Additional data are contained in Table 2 that indicate the vehicle mileage measured at most of the facilities listed in Table 1. A considerable difference exists between the plants and again is reflective of the different types of facilities and their layout. In some cases the plant layout leads to excessive vehicular travel through inefficient materials flow or location of employee parking facilities.

Particulate matter emissions can be calculated from the data presented in Tables 1 and 2. For discussion purposes calculations were made assuming all roads were either paved or unpaved. These estimates are presented in Table 3. In all but one case, the unpaved emissions exceeded the paved road emissions by an average factor of four. The exception to this was caused by the high surface loading at Plant C, essentially resulting in the paved road acting as an unpaved road.

TABLE 1. SUMMARY OF SURFACE CHARACTERISTICS OF ROADS[6]

Plant	Silt(%) Unpaved	Silt(%) Paved	Surface Loading (lbs/mile)
A	11.3	-	-
B	-	8.4	3,820
C	-	11.8	30,942
D	16.0	14.3	6,300
E	11.1	13.7	1,100
F	13.8	11.0	3,360
G	12.3	-	-
H	-	7.9	3,520
I	-	7.1	140
J	9.3	7.1	730
Composite Average	12.7	10.5	3,580

TABLE 2. AVERAGE DAILY VEHICLE MILEAGE TRAVELED BY VEHICLE TYPE[7]

Plant	Automobile	Trucks 2 Axle	Trucks 3 & 4 Axle	Trucks 5 & 6 Axle	Plant Equipment	Total
A	3,976	259	127	316	121	4,799
B	16,584	873	159	750	508	18,874
C	15,513	312	115	244	180	16,364
D	384	7	49	78	162	680
E	5,958	538	554	1,101	90	8,241
F	1,668	119	43	56	102	1,988
G	1,135	1,409	637	62	159	3,402
J	4,538	68	880	127	0	5,613
Typical Vehicle Weight (tons)	2	10	10-20	25	35	
Average Number of Wheels	4	5	7	11	16	
Average Vehicle Speed (mph)	20	15-20	15	15	10-15	

TABLE 3. ANNUAL FUGITIVE DUST EMISSIONS FROM MILLS AS ALL ROADS PAVED OR ALL ROADS UNPAVED

	Emissions (Tons/Year)	
Plant	Paved Road	Unpaved Road
A	655.0	2,275.6
B	2,229.3	9,979.7
C	17,798.6	6,766.9
D	504.6	1,119.3
E	633.8	3,330.6
F	301.2	1,283.5
G	895.8	3,186.3
J	116.6	2,254.4

COMPARISON TO FIELD DATA

The emissions inventory developed from Tables 1 and 2 are based on Equations 1 and 2. Recent field tests have indicated that the emission factors listed in Equations 1 and 2 are subject to high variability.[8,9] Agency discussion of this problem has resulted in field monitoring to verify the emission factors. Typical testing gear for these verifications consist of vertical sampling devices located along a roadway to capture the plume emitted by a moving vehicle. An earlier version of the testing device is shown in Figure 1 and its location is shown in Figure 2.

Field data collected at several facilities was investigated to determine how actual measured emission factors compared to those predicted using Equations 1 and 2. These data are listed in Tables 4 and 5 and statistical summaries are provided in Table 6.

Comparison of the actual measured emission factors to the predicted emission factors yielded the following relationships:

Paved Road

$$\text{Actual} = 0.43 \times \text{Predicted} + 4.08 \qquad (3)$$

Unpaved Road

$$\text{Actual} = 2.65 \times \text{Predicted} + 9.46 \qquad (4)$$

For the data contained in Table 6, the predicted emission factors were found to differ from the measured values by multiples of 0.90 and 4.44 for the paved and unpaved roads, respectively. Any open-dust emissions inventory for roads based on the published emissions factors would be expected to yield an underestimation of the actual emissions depending on the predicted emission factors as described by equations listed above.

A population distribution of different particle sizes occurs in the fugitive emission from roads. Aerodynamic equivalent diameters (AED) were determined from the emissions tests listed in Tables 4 and 5 and presented in Figure 3. An important factor in making an emissions trade is the trade for like-particulate matter and the subsequent adverse health potential of that trade. Inhalable sizes are an important consideration in making a determination as to the health risk of an emissions trade. From the results in Figure 3, particle size distribution is the same for both paved and unpaved roads at AED >12 µm. The cumulate distribution less than 15 µm AED is 77 percent of the total measured by the exposure profiler. At an AED >10 µm this drops to 52 percent for the paved road and 58 percent for the unpaved road.

DEVELOP THE EMISSIONS TRADE

Previous sections have discussed elements in developing the open-dust fugitive component of an emissions trade. Specific elements to follow are:

1. Determine traffic volume in the plant by conducting in-plant traffic survey and origin-destination study. When traffic summaries are determined from the traffic counts, then the origin-destination study

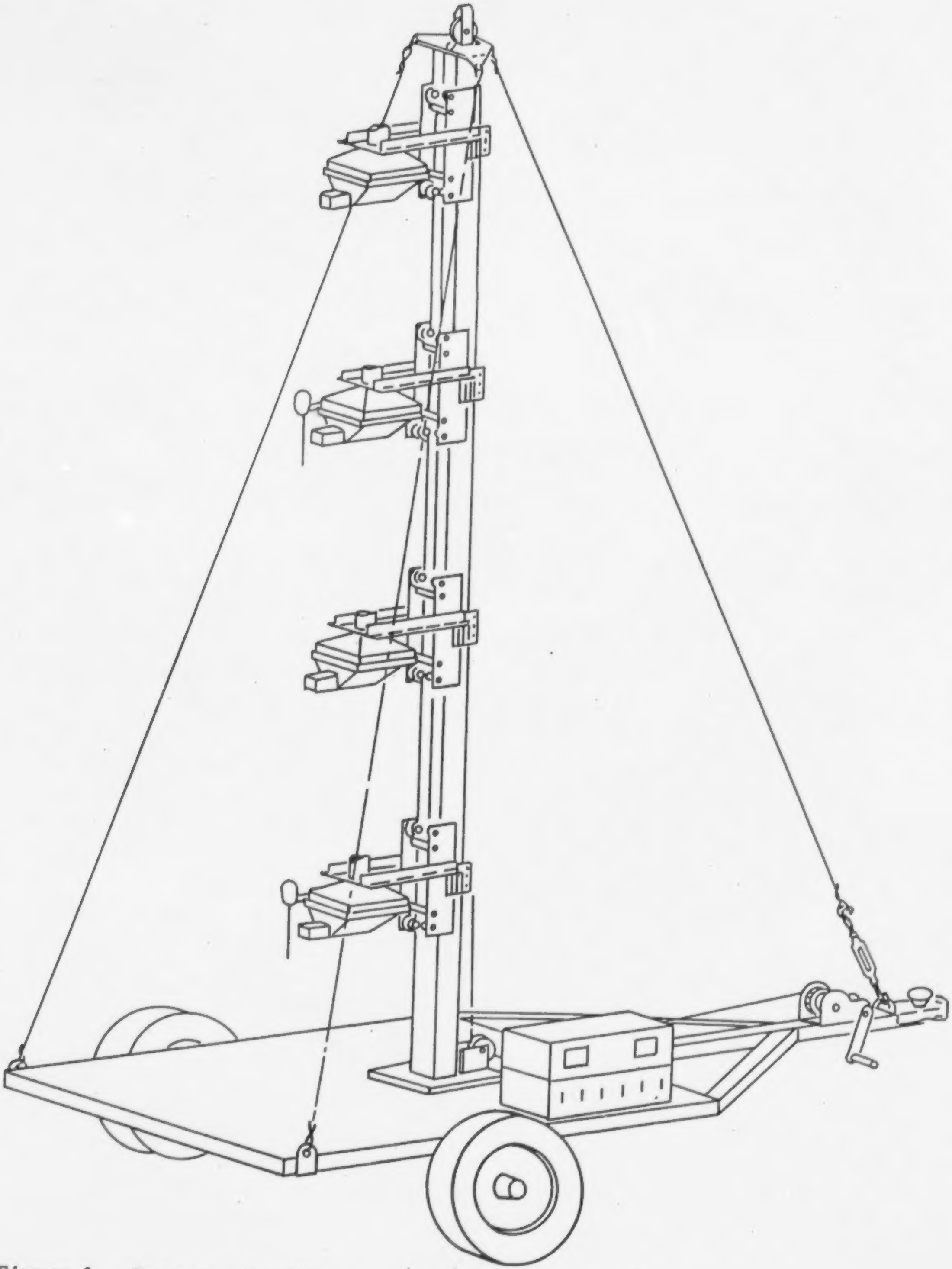


Figure 1. Exposure Profiler Device (adapted from 10)

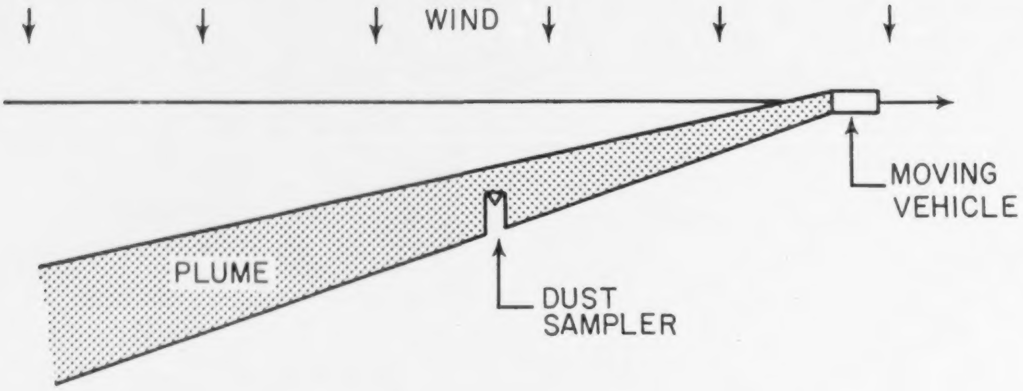

WIND
MOVING VEHICLE
PLUME
DUST SAMPLER

Figure 2. Simplified Layout of Testing Device (adapted from 10)

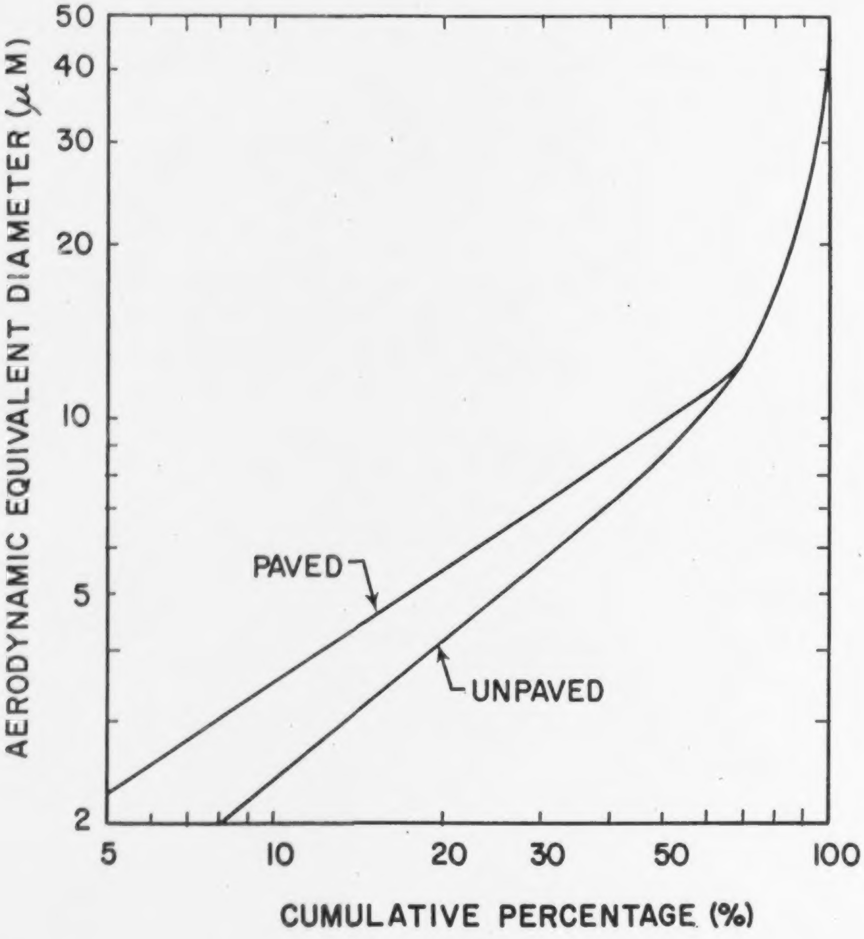


Figure 3. Cumulative Mass Distribution of Particles By Aerodynamic Equivalent Diameter

TABLE 4. LISTING OF PAVED ROAD EMISSION FACTORS[6,9,11]

Plant	Emission Factor (lb/VMT)	
	Predicted	Actual
B	0.44	1.70
	0.26	1.85
	0.71	0.59
	1.80	2.28
	0.70	0.42
	1.30	1.66
	0.67	0.10
	1.47	0.15
	1.81	0.13
C	5.00	17.80
	2.32	11.20
	3.02	8.40
	6.44	18.90
	24.62	8.80
	41.12	11.30
	37.44	26.70
	34.32	24.70
	38.20	12.00
	36.96	19.20
	45.18	32.30
	42.48	27.30
	31.16	17.30
D	0.29	0.91
	1.29	0.48
	1.04	1.33
	0.86	0.73
	0.18	0.07
	1.84	0.76
	1.51	1.66
	9.52	0.88
	11.31	0.80
	0.41	0.28
	0.41	0.79
E	0.38	2.25
	0.74	1.96
	1.00	0.91
	1.08	7.90
	1.14	1.41
	1.08	2.86
	1.34	4.74
	1.64	8.39
	0.38	17.77
	0.34	11.35
	0.40	10.27
	0.80	13.24
	0.76	18.76

TABLE 5. LISTING OF UNPAVED ROAD EMISSION FACTORS [6,9,11]

	Emission Factor (lb/VMT)	
Plant	Predicted	Actual
D	4.50	6.51
	3.20	2.73
	8.60	7.38
	5.19	10.49
	5.05	25.18
	5.22	41.95
	2.11	29.85
E	10.24	59.92
	17.33	51.25
	20.01	48.78
	18.15	69.57
	14.42	38.48
J	4.90	46.21
	1.81	19.04
	1.54	9.52
	1.32	20.97
	1.90	22.74
	0.79	11.62
	1.59	25.24
	0.57	31.19
	9.53	65.24

TABLE 6. COMPARISON OF ACTUAL AND PREDICTED FUGITIVE DUST EMISSIONS FROM ROADS

	Paved		Unpaved	
	Mean	σ	Mean	σ
Actual (lb/VMT)	7.84	8.72	29.18	20.82
Predicted (lb/VMT)	8.70	14.45	6.57	5.99
Number of Pairs	46		21	
Correlation Coefficient	0.72		0.71	
Least Squares Fit*				
Slope	0.43		2.65	
Intercept	4.08		9.46	

*Actual = Slope x (Predicted) + Intercept will yield the proper multiplier to use to scale the traffic data to full production levels.

2. Conduct exposure profile studies under existing conditions to determine the present emission factors. If this is not practical, then rely upon published emission factors, knowing the published emission factors are probably low.

3. Combine the above traffic summaries from 1 with the emission factors from 2 to yield a listing of fugitive dust emissions as shown in Table 7 and represented graphically by Figure 4.

4. Reduce the values in Table 4 to represent SIP required controls. If the plant is located in an attainment area, then generally no control program is mandated beyond good housekeeping. If the plant is located in a nonattainment area, then Reasonable Available Control Technology (RACT) must be put in-place before looking at emission reduction credits for an emissions trade.

5. Apply control technologies similar to those listed in Table 8 to develop the emission reduction credit.

From the results presented in Table 7, current emissions of fugitive dust from the roadways are presented. An emission reduction credit can be developed from this data. If a chemical dust suppressant is applied to the unpaved roads and twice-a-week vacuum sweeping is done, then the following emission reduction credit could be developed from the following equation:

$$ERC = U \times Cu + P \times Cp \qquad (5)$$

where ERC = emission reduction credit
U = current emissions from unpaved roads
Cu = efficiency of control technology for unpaved road
P = current emissions from paved roads
Cp = efficiency of control technology for paved road

Assuming Cu = 90 percent and Cp = 65 percent, an emission reduction credit of 125.6 pounds per hour is developed.

CONCLUSIONS

An emissions trade of fugitive particulate matter from open-dust sources for process fugitives can be accomplished through a structured approach to quantification of the emission reduction credit. Emission factors for open dust sources can be used as a first approximation of the emissions. However, field data have shown the emission factors differ by a multiple of 0.90 for paved roads and 4.44 for unpaved roads. An exposure profiler test is recommended to quantify the emissions under current and proposed controls as part of an emission trading application.

TABLE 7. SUMMARY OF CHARACTERISTICS AND PARTICULATE MATTER EMISSION RATES OF ROADS AT IRON AND STEEL PLANT

Roadway* Section	Roadway** Type	Length (Miles)	Vehicle Miles/Day	Emissions Rate (lb/hr)
A	P	0.24	220.2	6.8
B	P	0.20	21.3	1.1
C	P	0.08	5.7	0.2
D	P	0.15	209.9	5.9
E	P	0.29	32.5	0.4
F	P	0.06	12.9	1.6
G	P	0.15	308.0	2.5
H	P	0.06	5.6	<0.1
J	P	0.10	319.2	3.4
K	P	0.15	57.1	1.4
L	P	0.10	26.6	0.1
M	P	0.30	3.7	<0.1
N	P	0.20	528.8	1.7
O	P	0.21	395.5	1.5
P	P	0.40	781.0	28.1
R	P	0.07	4.7	<0.1
S	P	0.27	297.3	4.0
T	P	0.14	159.3	1.6
U	P	0.50	1068.0	16.0
V	P	0.20	243.4	3.0
W	P	0.05	37.8	0.5
X	P	0.12	196.6	10.9
Y	P	0.48	393.0	16.3
Z	P	0.05	18.5	78.6
A-A	U	0.27	67.7	4.0
B-B	U	0.20	24.2	1.5
Total		5.04	5438.5	191.1

---

* Designation corresponds with that used in Figure 4

** P=paved, U=unpaved

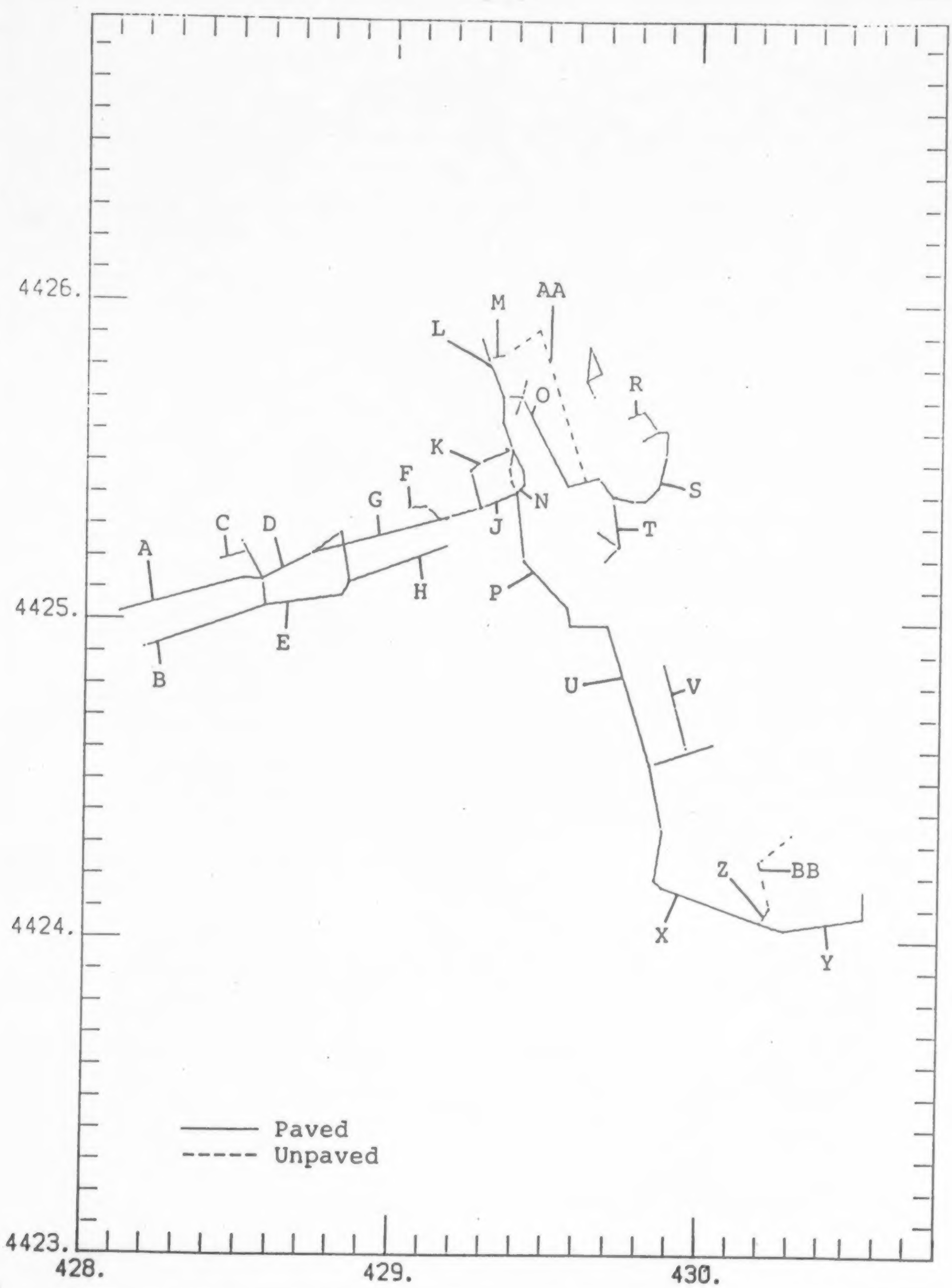

4426.
4425.
4424.
4423.
428.
429.
430.
A
B
C
D
E
F
G
H
J
K
L
M
AA
N
O
P
R
S
T
U
V
X
Y
Z
BB
Paved
Unpaved

Figure 4. Paved and Unpaved Roads at Iron and Steel Plant

TABLE 8. SUMMARY OF CONTROL EFFICIENCIES

Control Measure	Percent Emission Reduction[9,11]
1. Paving and daily vacuum sweeping	90-95
2. Application of Coherex to unpaved road	90-95
3. Paved road (moderately dusted) - daily vacuum sweeping	80-85
4. Paved road (moderately dusted) - biweekly vacuum sweeping	60-70
5. Paved road (heavily dusted) twice-per-day vacuum sweeping	45-50

Note:		
	lightly dusted	<200 pounds per mile
	moderately dusted	200 - <750 pounds per mile
	heavily dusted	>750 pounds per mile

REFERENCES

1. U.S. EPA, "Air Pollution Control; Recommendation for Alternative Emission Reduction Options Within SIP; Policy Statement," 40 CFR Part 52, December 11, 1979, pp. 71780.

2. A. Gorsuch, "Emissions Trading Policy Statement: General Principles for Creation, Banking, and Use of Emission Reduction Credits," U.S. EPA, April 2, 1982.

3. U.S. EPA Compilation of Air Pollutant Emission Factors, Third Addition, PB-289488 August 1977 (Including Supplements 1-8).

4. Cuscino, Thomas A., Jr. Particulate Emission Factors Applicable to the Iron and Steel Industry. EPA-450/4-79-028, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, September 1979. 83 pp.

5. Hanson, G., communication with L.L. Simmons, December 1981.

6. Simmons, L.L., Norton, C.L., and Edmonds, P.R., "Practical Aspects of Matching An Emissions Inventory to an Air Quality Dispersion Model," Proceedings Emission Inventories and Air Quality Management Specialty Conference, April 27-30, 1982, p. 85-96.

7. Melczak, R. communication with L.L. Simmons, July 1982.

8. T.A. Cuscino, Jr., C. Cowherd, Jr. and R. Bohn, "Fugitive emission control of open dust sources," EPA Symposium on Iron and Steel Abatement Technology for 1980, Philadelphia, Pennsylvania (November 1980).

9. Maser, J.A., Norton, C.L., and Simmons, L.L., "Uncontrolled and Controlled Emissions from Nontraditional Sources in a Coke and Iron Plant: A Field Study Analysis," Energy Impact Associates, APCA Specialty Conference: Air Pollution Control in the Iron and Steel Industry, April 21-23, 1981.

10. Cowherd, Chatten, Jr., Russel Bohn, and Thomas Cuscino, Jr. Iron and Steel Plant Open Source Fugitive Emission Evaluation. EPA-600/2-79-103, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, May 1979. 139 pp.

11. United States Steel Corporation, "A Study of Controlling Fugitive Dust Emissions from Non-Traditional Sources at the United States Steel Corporation Facilities in Allegheny County, Pennsylvania," submitted to Allegheny County Bureau of Air Pollution Control, December 1981.

A COMPARISON OF ALTERNATIVE COKE PUSHING EMISSION CONTROL SYSTEMS

by: Daniel J. Metzger
Nona L. Hancock
National Engineers and Associates
St. Louis, Missouri 63105

The work described in this paper was not funded by the U.S. Environmental Protection Agency. The contents do not necessarily reflect the views of the Agency and no official endorsement should be inferred.

ABSTRACT

The need to control emissions evolved during the pushing of coke from a coke oven has given rise to a variety of control systems. This paper compares three of the most popular systems in use today. The three systems examined are: Mobile Systems, Traveling Hood Systems, and Coke-side Shed Systems.

The comparisons made in this analysis are those associated with the kinds of choices facing the end user. The content of this paper is, therefore, directed toward the engineering and physical aspects of the systems.

The data presented is based on three of the systems available from National Engineers and Associates. Capital, operating, maintenance, and other related costs of the three systems may vary from systems engineered and erected by others.

All three of the coke pushing emission control systems which are the subjects of this comparison have been successfully applied to meet the regulatory requirements. As with many air pollution control tactics, the regulatory requirements have evolved and changed over time. For this reason, an understanding of the basic strengths and limitations of each type of control system is of importance to both the public and private sectors involved in control of air contaminants.

DESCRIPTION OF CONTROL SYSTEMS

A Mobile Pushing Control System is a complete gas cleaning system consisting of components which work together to capture and clean coke pushing emissions. The complete system includes the following components: (1) an articulated hood which encloses the coke guide mounting on the coke-side bench of the coke ovens, mechanism for raising and lowering the hood; the hood travels with and is attached to the coke guide and is moved along the bench by the door machine; in the lowered position, the articulated hood mates with the top of a one-spot coke receiving car so that when the hood is in the lowered position, an enclosed passageway exists from the coke oven, through the coke guide, and into the coke receiving car; (2) a one-spot coke receiving car mounted on a special rail car which is capable of containing an oven-load of coke without being moved along the track during the push; (3) a self-propelled gas cleaning car consisting of a special railroad car, traction motors and contols which contain the gas cleaning equipment, exhaust fan, diesel engine to supply power to the exhaust fan and pumps, piping, controls and other equipment. Coke is pushed through an enclosed coke guide designed to closely mate with the receiving car into the one-spot coke receiving car. As the push occurs, the dirty gases are drawn from the guide and coke receiving car through the ductwork into a wet venturi-type scrubber and air-water separator where the solid particulate in the gases are removed. The principal methods used to create the volumetric air flow needed for the capture and cleaning of the gases is a diesel engine driven fan. Depending on the particular design, steam or compressed air eductors have been used. Evacuation through the coke receiving car usually continues until the quench cycle is commenced.

The Traveling Hood System usually consists of a hood that either covers the coke receiving car or the space above a conventional quench car and mates with an enclosed guide. The hood connects to a duct which in turn is connected to a land-based gas cleaning system located at a convenient place near the battery. During the push, gases are drawn from the coke guide and receiving car into the hood where the gases are channeled to the exhaust duct. The gas cleaning systems that are in use with traveling hood systems include baghouses, venturi scrubbers, and wet electrostatic precipitators. Two methods are used to connect the hood to the duct: (1) individual dampered ports; (2) a belt sealed duct with a trolley that lifts the belt as it travels along the duct. The belt sealed method allows the flexibility to capture emissions during travel to the quench tower whereas the bench mounted hood has substantial limitations for control of travel emissions.

A third subject system is the Coke-side Shed. This system is comprised of a stationary hood which encloses the coke-side bench, coke-side oven machinery, and extends over the quench tracks of the battery. Longitudinally, the stationary hood or shed extends the length of the coke battery plus an additional length to capture the pushing emissions. The shed concept is simple: allow the gases emitted during the push to rise naturally and fill the shed, then evacuate the shed. A baghouse, electrostatic precipitator, high energy wet scrubber, or other gas cleaning devices can be used to remove the solid particulate matter from the pushing emissions.

ADVANTAGES AND DISADVANTAGES

An examination follows of some of the advantages and disadvantages of each system.

Mobile control systems are reasonably compact for the amount of machinery and equipment required, and can be adapted for use on coke batteries with close clearances. If properly designed, mobile systems will evacuate and clean the emissions from a push with a minimum of exhaust air. National Engineers' system has consistently proven that evacuation of coke pushing emissions from a 4-meter coke oven can be accomplished with less than 50,000 d.s.c.f.m. of exhaust air. Installation is simple when compared to the other systems, and the only production loss which may occur during installation occurs when the coke guides are changed or retrofitted with enclosures. Delays may also be encountered if the quench tracks are not designed for the increased loads and have to be replaced. Mobile systems are complex, and experience has shown these systems to require more maintenance attention than the other two systems. Installation usually requires the purchase of a new one-spot coke receiving car and either a new enclosed coke coke with an articulate hood or an extensive retrofitting of an existing guide plus the purchase of the self-propelled gas cleaning car. The mobile system has considerably more mass than a conventional quench car and quench locomotive. The increased mass of the system will increase the acceleration and deceleration time of the system which may, depending on the distance the coke has to be moved for quenching and dumping, affect the coke pushing cycle of the battery.

Traveling hood systems offer the advantage of close hooding and land-based gas cleaning equipment. The hood can be designed for either conventional coke quench cars or for one-spot coke receiving cars. The hood for a one-spot car is quite small compared to a hood over a conventional quench car. Usually the coke guide can be modified to interface with the hood. This hood is moved by either the quench locomotive, an endless cable reversible pulling device, or the door machine. A very large and powerful door machine is required to adequately handle the hood, if this means of moving the hood is used. If two door machines are required to maintain production levels, two hoods will be required.

The hood is fitted as closely as feasible to the coke guide and coke receiving car so the exhaust requirements of the gas cleaning system, while greater than the mobile system, are minimized. Proper evacuation of the guide and receiving car can be achieved with 100,000 to 150,000 d.s.c.f.m. of exhaust air, depending on system design and hood configuration. This volumetric air flow can be reduced if a one-spot receiving car is used.

Since the gas cleaning equipment can be located remote from the battery, the system lends itself to the use of various kinds of gas cleaning equipment; although, a baghouse seems to be the preferred equipment for this purpose.

Addressing the disadvantages, an extensive structure is required to support the hood, the trolley for the conveyor sealed duct, and the collection duct; therefore, delays in production can occur during construction of the structure near the quench tracks. Similar, but more extensive, interferences with coke production can occur during the installation of a coke bench-mounted hood. Since the hood extends over the quench tracks, maintenance on the hood may be more complicated and may interfere with production.

In recent years, the coke-side shed has gained new acceptance as a viable coke pushing control device. Other than individual components of the gas cleaning system, there are few moving parts to fail. The shed structure is passive, requires little maintenance except periodic structural maintenance, and has a life expectancy without a major rehabilitation much greater than either the mobile or traveling hood system. The shed generally presents an interference when a buckstay must be replaced or when work requiring a large crane must be performed under the enclosure; however, proper design and planning can minimize these problems and make the performance of this work quite feasible.

Construction of the shed requires continuing communication between the constructor and coke plant operating personnel if production losses during construction are to be kept to a minimum. Because the hot coke pushing emissions expand in the volume of the shed, a considerably larger volumetric flow of exhaust air and companion gas cleaning equipment must be installed and maintained. While wet gas cleaning devices have been used for shed installations, the baghouse can be expected to be the most efficient and least costly equipment for this use.

Careful analysis, design, and selection of baghouse module design, bag design, number of bags per module, type of bag material selected, exhaust fans, and operating controls creates operating flexibility, increased on-line operating time, decreased operating and maintenance costs, decreased initial capital costs, and improved reliability of the gas cleaning equipment and proper evacuation of the shed.

The size of the gas cleaning system will vary depending on the particular design of the shed and the coke oven height. The most recent development in the design of coke-side sheds is zoning of the exhaust air to direct it to where it is most needed as the time it is most needed. This development is revealed in U.S. Letters Patent No. 4,330,372*, entitled "Coke Oven Emission Control Method and Apparatus."

The zoning development is a proven means to provide proper emission capture and evacuation of a coke-side shed utilizing the least amount of volumetric air flow. Utilizing the zoning development, a coke-side shed on a battery of 4-meter coke ovens can be controlled with less than 200,000 a.c.f.m. of exhaust air.

SELECTION OF COKE PUSHING CONTROL SYSTEM

The selection of the coke pushing control system best suited for a particular coke oven battery is not merely a matter of personal preference, initial capital costs, or maintenance costs. Many factors must be considered before a proper selection can be made. Perhaps the single most influential factors are the performance criteria to be met by the system. These criteria are established by air pollution regulations and/or court

*United States Patent No. 4,330,372, Coke Oven Emission Control and Apparatus; Inventors: Donald P. Cairns and Daniel J. Metzger.

orders. If the regulation requires the gas cleaning system to have an outlet loading of less than .02 grains per dry standard cubic feet, then a wet venturi-type scrubber can generally be eliminated. If the opacity of the emissions emitted during the transportation of coke to the quench tower is greater than the allowable levels, then a system must be chosen which is capable of capturing the emissions.

Some regulations of coke pushing emissions call for controlling emissions immediately when the coke-side door is removed. This complicates the use of mobile and traveling hood systems, except where one-spot door machines are used or extensive auxiliary ductwork is utilized to capture door removal emissions, if any. If a requirement of coke oven operation is that no coke pushing may be performed unless an emission control system is available and on-line to control the emissions, then system choices become more difficult. If this latter condition is an absolute requirement, the on-line performance of a system may be the determining factor. A coke-side shed generally has an an on-line performance of 99+ percent. Mobile systems have an on-line perentage of 90-95 percent, and traveling hood systems have an on-line percentage of 95-98 percent. These measures of reliability are based on the design of National Engineers' systems.

Regulations may require an installed spare system when either a mobile or traveling hood system is used. If door leaks and other fugitive emissions are a problem, then a coke-side shed may be the most appropriate system; however, experience has shown that special design considerations must be made including additional equipment and changes in the operation of the baghouse.

Other considerations may also influence the type of system to be used. A particularly tight clearance envelope may eliminate use of the mobile or traveling hood system. On the other hand, the yard conditions and location of existing structures may prevent the erection and construction of a coke-side shed. The zoning development, previously discussed, limits the amount of electrical energy required compared to previous designs; nevertheless, electric power demand is a factor requiring close analysis. Other influencing factors are: the current pushing schedule of the facility; future expansion plans; and possible disposal problems for the wastes of the gas cleaning devices.

CAPITAL COST COMPARISONS

Capital cost is a major consideration in the selection of a pushing control system. For this reason, a comparison of the three systems is presented. The costs are for completely engineered systems furnished on a turnkey basis. It will be assumed that adequate power is available at the motor control house and that no extensive demolition is required for each installation.

The cost estimates are based on 1982 costs and application to 4-meter coke ovens as a retrofit.

Mobile Pushing Control System

Engineering and Fabrication:			
Gas Cleaning Car	$2,500,000	-	$2,650,000
One-spot Car	950,000	-	1,125,000
Hooded Coke Guide	300,000	-	330,000
Assembly Cost:	225,000	-	275,000
Miscellaneous Sub-Systems:			
Re-fuel Tanks, etc.	95,000	-	110,000
One-spot Quench System	35,000	-	45,000
Total Installed Cost	$4,105,000	-	$4,535,000

One mobile system can be expected to service a 4-meter coke battery consisting of 150 ovens with no change in the pushing schedule.

Traveling Hood System

Engineering and Fabrication:
including Hood, belt sealed duct, trolley, support structure;
Coke guide modifications;
Baghouse gas cleaning system, complete with exhaust fans.
$2,650,000 - $2,775,000

Erection and Construction:
including Foundations;
Erection and installation of components;
Baghouse gas cleaning system, with exhaust fans.
$1,775,000 - $1,875,000

Total Installed Cost $4,425,000 - $4,650,000

The above figures are based on a traveling hood system capable of servicing a single 4-meter coke battery of approximately 50 ovens.

Coke-side Shed

Engineering and Fabrication:
including Structural steel, stainless steel sheeting, required ductwork;
Baghouse with gas cleaning system, complete with exhaust fans. $2,825,000 - $2,950,000

Erection and Construction:
including Foundations, structural steel, ductwork;
Baghouse gas cleaning system, with exhaust fans.
$1,775,000 - $1,920,000

Total Installed Cost $4,600,000 - $4,870,000

The above figures are based on a zoned coke-side shed for a single 4-meter coke battery of approximately 50 ovens.

OPERATING AND MAINTENANCE COST COMPARISONS

The operating and maintenance costs of any of the three coke pushing emission control systems must be considered when comparing the systems. The operating and maintenance cost estimates presented are based on 1982 costs.

Mobile System

	Range		
Maintenance (Materials and Labor)	$1,000,000/yr.	-	$1,300,000/yr.
Operating Cost including Electricity Diesel Fuel Water Lubrication	$ 67,125/yr.	-	$ 80,000/yr.
Total per year	$1,067,125/yr.	-	$1,380,000/yr.

Traveling Hood System

Maintenance (Materials and Labor) includes a baghouse cleaning system	$ 47,600/yr.	-	$ 70,000/yr.
Operating Cost including Electricity Particulate dust removal Lubrication	$ 230,900/yr.	-	$ 400,000/yr.
Total per year	$ 278,500/yr.	-	$ 470,000/yr.

Coke-side Shed

Maintenance (Material and Labor) includes a baghouse cleaning system	$ 42,200/yr.	-	$ 70,000/yr.
Operating Cost including Electricity Pre-coat material Particulate dust removal Lubrication	$ 310,300/yr.	-	$450,000/yr.
Total per year	$ 352,500\yr	-	$520,000/yr.

ERECTION AND CONSTRUCTION TIMING

Any coke producing facility contemplating the installation of a coke pushing control device is usually faced with a rigid timetable required for the installation. While system evaluation is a time consuming process, the installation timetable should be recognized and taken into consideration.

Past performance is usually the basis for any estimated construction schedule. Almost any shcedule can be shortened, but the costs associated with the change will be reflected in the total project cost to the coke plant. The timetables presented here reflect a minimum schedule from beginning design work to commissioning the system. When the economy takes an upturn, deliveries of equipment and fabricated items may increase the schedule shown below.

Mobile System (150 coke ovens)	14 - 24 months
One gas cleaning car	
One coke receiving car	
One hooded coke guide	
Land-based System (50 coke ovens)	9 - 18 months
One movable hood and trolley duct	
One coke guide	
One baghouse	
Coke-side Shed System (50 coke ovens)	11-18 months
One shed and auxiliary materials	
One baghouse	

OPERATOR AND MAINTENANCE PREFERENCES

Previously it was stated that the selection of a pushing control system was not just a matter of personal preference. That is not to say that personal preferences should not be taken into consideration. Many times, a personal preference by an operator is based on past experiences about what will and will not function in a particular plant. Most plant operating and maintenance personnel are aware of their strengths and weaknesses relating to operation and maintenance.

Most preferences will usually be directed at the particular pieces of equipment to be furnished. Some plants may have preferences for the use of baghouses or electrostatic precipitators, in which case, the pushing control system chosen must be compatible with the preferred gas cleaning system.

In any case, the operating and maintenance personnel make a significant contribution to the system selection process.

SUMMARY

Three coke pushing emission control systems are compared based upon varying circumstances. These three systems are: (1) mobile, rail mounted; (2) traveling hood; (3) coke-side shed. The components of each system are stated, and the basic operation for emission control is described. Advantages and disadvantages of each system are presented from a functional standpoint as well as against the government regulatory framework. Considerations for system selection are suggested. A comparison of capital costs in 1982 dollars for 4-meter coke ovens are given for each type of system. An estimate of erection and construction items is presented. Finally, a note is made about the part operator and maintenance preferences should play in the selection of a system and the final design of that system.

The work described in this paper was not funded by the U. S. Environmental Protection Agency. The contents do not necessarily reflect the views of the Agency and no official endorsement should be inferred.

THE PRECISION OF VISUAL EMISSION OBSERVATIONS WITHIN AN INTEGRATED STEEL WORKS

by: D. E. Splitstone and J. Y. Lin
United States Steel Corporation
Research Laboratory
125 Jamison Lane
Monroeville, Pennsylvania 15146

ABSTRACT

Visual observation of "smoke" is probably one of the oldest measures of source emissions. Attempts to quantify this measure have proceeded from the use of the "Ringelmann Chart" to the certification of an observer's ability to quantify source emissions to 5 percent increments of opacity. Many regulatory and source-emission standards, today are based on the ability of observers to quantify visual emissions. However, analysis of data for the simultaneous observation, under actual field conditions, of various source types by several certified observers reveal that there is significant variability among the observers' perception of the opacity of source emissions. This variability is a significant portion of the precision of the measurement method. This precision is shown to vary with the diffusivity of the smoke emission, ranging from 3.6 percent opacity for well-defined emissions to 6.7 percent opacity for more diffuse emissions.

The precision of this measurement method should be taken into account when determining possible violations of applicable opacity standards. Better still, these standards should be stated in such a manner as to explicitly recognize the precision of this measurement method as part of a criteria for compliance determination.

INTRODUCTION

The regulation of the emission of air pollutants on the basis of the visual perception of smoke has a history as long as the history of air-pollution regulation. Prior to 1881 and the enactment of municipal legislation in Chicago, Illinois, and Cincinnati, Ohio, smoke was considered a common nuisance. It had to be proven in each individual case that smoke was injurious or offensive to the senses. With the enactment of this initial legislation smoke became a nuisance *per se*.1)*

---

* See References.

This early legislation prohibited smoke that was defined variously as "dense," "black," or "gray." Problems associated with the definitions of "dense," "black," or "gray" led to the adoption, in 1919, of a standardized method for defining smoke density—the Ringelmann Chart—by its inclusion in a smoke ordinance for the city of Boston passed by the Massachusetts Legislature.2) Court challenges to the use of the Ringelmann Chart in Los Angeles County Rule 50 or Section 24242 of the California Health and Safety Code during the 1950's in People Versus International Steel Corporation and People Versus Plywood Manufacturers of California resulted in a ruling that a trained inspector need not have a Ringelmann Chart in his possession while observing smoke plumes.2,3)

The system developed by Maximilian Ringelmann in the late 1800's provides a consistent method of reproducing shades of gray from all white to black.4) Although use of the Ringelmann Chart permits the classification of plumes in terms of degrees of grayness, it does not provide for the situation in which a plume may be light gray but is as difficult to see through as a plume classified as dark gray or black by the Ringelmann system. Los Angeles County Rule 50 addressed this problem by inclusion of an equivalent-opacity section. This section condemns smoke or any other contaminent that is at least as hard to see through as smoke that is as dark as or darker than a Ringelmann No. 2.3)

Equivalent opacity is defined as the percent of light transmitted through a plume of specific grayness as defined by the Ringelmann Chart. The six reference shades of gray going from white to black correspond to six 20 percent increments of opacity going from 0 to 100 percent. In upholding Los Angeles County Rule 50, the courts also laid a foundation for observers trained in measuring equivalent opacity to be considered experts in the use of this measurement method.

All 55 states and territories now have as part of their State Implementation Plans some form of regulation of visible emissions which employs either a Ringelmann Chart number or percent equivalent opacity. The New Source Performance Standards (NSPS) promulgated by the U. S. Environmental Protection Agency (EPA) also specify limitations of source emissions in terms of equivalent opacity.5) The proliferation of regulations limiting the visual opacity of emissions and the potential cost of meeting these regulations certainly justify another look at the precision of the measurement method.

CERTIFICATION OF OBSERVERS

The procedure to be used in the training and certification of equivalent-opacity observers is well specified.6) Briefly a person seeking certification becomes familiar with both black and white smoke of known densities. After familiarization the prospective observer is given the practice of observing 25 black and 25 white smoke plumes of various shades. Upon completion of the practice session a test is conducted, again employing 25 black and 25 white smoke plumes of various shades. The prospective observer continues the process until he qualifies as an expert smoke reader by demonstrating that he can read both black and white smoke with an average error not to exceed 7.5 percent opacity in each category and with an error not to exceed 15 percent opacity on any reading in each category. Certification must be renewed via this same procedure every six months. The standard used to train and test the observers is a calibrated transmissometer in the smoke-generator stack.

ACCURACY OF METHOD

The description of EPA Method 9 in the Federal register reports that studies have been conducted "...to determine the magnitude of positive errors which can be made by qualified observers while reading plumes under contrasting conditions....."[6] The results of these studies are

> "(1) For black plumes (133 sets at a smoke generator), 100 percent of the sets were read with a positive error of less than 7.5 percent opacity; 99 percent were read with a positive error of less than 5 percent opacity. (2) For white plumes (170 sets at a smoke generator, 168 sets at a coal fired power plant, 298 sets at a sulfuric acid plant), 99 percent of the sets were read with a positive error of less than 7.5 percent opacity; 95 percent were read with a positive error of less than 5 percent opacity."[6]

The definition given for positive error is the average opacity determined by the observer's 25 observations minus the average opacity determined from the transmissometer's 25 recordings.[6] The Federal Register account concludes that "The positive observational error associated with an average of twenty-five readings is therefore established."

To the jaundiced eye of a statistician, all that has been established by these studies is that it is quite likely that the positive deviation of an average of 25 observer's observations from the average of 25 concurrent transmissometer readings is less than 7.5 percent opacity. Nothing is actually stated regarding the accuracy or precision of the measurement method.

A notable study was conducted by Hague, et al. between 1970 and 1978.[7] For this study 250 observers were asked to read generated smoke plumes under simulated field conditions. Only 40 percent of those certified observers tested were capable of meeting the Method 9 criteria of passing both black and white smoke tests. Hague also attempted to correlate test scores with factors such as observer age, frequency of method use, years of experience, use of glasses, time since recertification, sky cover, solar angle, wind speed, and wind direction. Though Hague reports that the correlations of test scores with these factors are weak, his data indicate the existence of significant positive reader bias for both white and black smoke plumes.

A ruggedness test of the measurement method was conducted by Weir et al.[8] They conclude that the observer's preception of plume opacity can vary from 14 to 87 percent depending only on the geographic location of the source and the time of day. Though this work was criticized by Goodwin,[9] Weir's rejoinder[10)] points out that in EPA field studies "...observers differed from the meter by more than 10 percent opacity" two thirds of the time.

Of these studies, Hague's comes the closest to permitting some meaningful statistical description of the accuracy and precision of the equivalent-opacity measurement method.

PRECISION OF THE METHOD

Several sets of opacity observations have been taken, for a variety of reasons, for different types of facilities within U. S. Steel in the recent past. Some of these sets of observations were made by multiple observers, from both government and industry, reading opacities for the source at the same time from essentially the same position with respect to the source. Three of these sets are deserving of further consideration. These are (1) readings taken of two coke-battery stacks by up to four observers, (2) readings taken on a teeming aisle-roof monitor by three observers, and (3) readings taken of casthouse emissions by seven observers. These three sets of observations, all read by observers with current certification, permit the assessment of the precision of field measurements of equivalent opacity for sources of different complexity.

To facilitate this assessment the mathematical model underlying the statistical analysis is based on the following considerations. Let M represent the true mean equivalent opacity of the observed source. At the time of observation of the i^{th} 15-second interval, the true opacity will be $M + P_i$, where P_i is defined as a deviation from the mean, M.

Suppose Y_{ij} is the equivalent opacity as measured by the j^{th} observer for the i^{th} 15-second interval. Then the difference between the observed opacity Y_{ij} and the true opacity $M + P_i$ will consist of two parts: a systematic error R_j, peculiar to the j^{th} observer, and a random reading error e_{ij}. This can be expressed as

$$Y_{ij} - (M + P_i) = R_j + e_{ij}$$

or

$$Y_{ij} = M + P_i + R_j + e_{ij},$$

where i = 1...p (periods) and j = 1...r (readers).

By imposing the restrictions $\sum_{i=1}^{p} P_i = \sum_{j=1}^{r} R_j = 0$, M is uniquely defined.

The constants M, P_i, R_j and e_{ij} are unknown but can be estimated from the data. It is assumed that the random reading errors, e_{ij}'s, are independent and come from the same population of errors. This population is assumed to have mean zero and variance σ^2. If the further assumption is made that the observers were chosen at random from the population of certified observers then the following analysis-of-variance table may be constructed.

	Analysis of Variance	
Source	Degrees of Freedom	Expected Mean Square
Among 15-sec. periods	$p - 1$	$\sigma^2 + r\sum_{i=1}^{p} \frac{p_i^2}{(p-1)}$
Among observers	$r - 1$	$\sigma^2 + p\sigma_r^2$
Observer error	$(p-1)(r-1)$	σ^2

The component of the variance denoted by σ^2, as explained above, represents the variance of the population of random reading errors. Thus σ will be a measure of the precision of an equivalent opacity reading made by an observer. The variance component σ_r^2 is average value of the square of the observer deviation from the period average equivalent opacity. Thus σ_r^2 is a measure of the variation introduced by the observer. The precision of a single equivalent-opacity reading is, then, a function of the observer's ability to reproduce a given opacity reading, σ^2, and the variation introduced by the observer, σ_r^2. The precision of this single reading may be expressed as $(\sigma^2+\sigma_r^2)^{1/2}$. The individual variance components σ^2 and σ_r^2 may be estimated by equating the expected mean squares in the analysis-of-variance table to their estimates.

The analyses of variance for the two coke-battery stacks are presented in Table 1. Note that there are significant differences due to observers regardless of stack. Pooling the sum of squares for observer error for the two stacks, an estimate of 12.03 is obtained for the observer variance component, σ^2. Thus the precision, σ, for an individual observer is estimated to be 3.47 percent opacity. Similarly, pooling the sum of squares due to different observers for the two stacks, an estimated variance component due to different observers, σ_r^2, becomes 3.75. Thus, if one considers the variance of a single opacity reading for a stack prior to the choice of the observer and the making of an observation it will be $\sigma^2 + \sigma_r^2$. The estimate of this variance is then 12.03 + 3.75 = 15.78. The estimated precision is 3.97 percent opacity. The width of a 95-percent-confidence interval may be estimated for a single reading by $2 \cdot 1.96 \cdot (\sigma^2 + \sigma_r^2)^{1/2}$. This width is 15.57 percent opacity. Thus, considering precision alone, one is 95 percent confident that for a stack the true observer reading is within ±7.8 percent opacity.

If the data summarization prescribed by Method 9 is used, that is, to average 24 consecutive observations,6) the precision of the average opacity is given by $\left(\sigma^2/24 + \sigma_r^2\right)^{1/2}$. Using the estimates from the stack observations this becomes 2.06 percent opacity. One is 95 percent confident that the true Method 9 observer average reading is within ±4.0 percent opacity.

TABLE 1. ANALYSIS OF VARIANCE
Coke Battery Stack No. 1

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F-Statistic
Period Effect	474	185505.08	391.36	
Observer Effect	3	5915.19	1971.73	165.56*
Reading Error	1324	15768.14	11.91	
	1801	207188.41		

Analysis of Variance
Coke Battery Stack No. 2

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F-Statistic
Period Effect	461	153536.80	333.05	
Observer Effect	3	4648.29	1549.43	127.45*
Reading Error	1355	16472.54	12.16	
	1819	174657.63		

*Significant at the 0.001 level.

Hague, et al., in their study defined the variables of white smoke score (WSM) and black smoke score (BSM) to be the average error or bias obtained in 25 readings of white smoke and black smoke, respectively, when observers' readings were compared with transmissometer readings.7) They presented as part of their findings the following means and standard deviations:

	Mean	Standard Deviation
WSM	6.21	2.16
BSM	5.52	1.78

Note the similarity between the estimated precision from the coke-battery stacks for the average of 24 readings (2.06) and Hague's standard deviation estimates for white and black smoke scores. Assuming an average bias of 5.87 percent opacity as found by Hague, one is 95 percent confident that the true Method 9 average opacity will be overestimated by a certified observer by from 1.87 to 9.87 percent opacity.

The analysis of variance for observations made of teeming-aisle emissions is given in Table 2. The variance component for reading error is estimated to be 12.23, which is quite close to the 12.03 estimated for the coke-battery stacks. Even though there exists a significant difference between observers, the variance component for observers is estimated to be only 0.84. The small variance component for observers for this source is probably due to the sequential nature of the teeming operation that would result in a concentrated emission. Thus readers instructed to read the darkest emission from the roof monitor would quite likely perceive the same smoke as being darkest.

The analysis of variance for the casthouse observations is given in Table 3. Again there is a significant difference between observers. The variance-component estimates for this source, however, are quite different from those for the stacks or teeming aisle. The variance-component estimate for reading error is 32.45, or almost three times that for the stacks and teeming aisle. The between-observer variance component is estimated to be 12.0 Because the emissions from the casthouse are more diffuse than those for the other two source types, this is not surprising. The observers may well perceive different smoke plumes as being the darkest.

The variance-component estimates for all three sources and the associated precision estimates for a single equivalent-opacity reading and a Method 9 average reading are given in Table 4. Note that the formula for calculation of precision from the variance components,

$$\text{Precision} = (\sigma^2 + \sigma_r^2)^{1/2}$$

implies that the precision may be represented as the hypotenuse of a right

TABLE 2. ANALYSIS OF VARIANCE
Teeming Aisle

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F-Statistic
Period Effect	2407	316985.0	131.69	10.77*
Observer Effect	2	4070.5	2035.23	166.37*
Reading Error	4814	58888.9	12.23	
Total	7223	379944.4		

TABLE 3. ANALYSIS OF VARIANCE
Casthouse

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F-Statistic
Period Effect	443	22746.85	5134.73	158.25*
Observer Effect	6	32081.95	5346.99	164.79*
Reading Error	2658	86246.61	32.45	
Total	3107	23930.13		

*Significant at the 0.001 level.

TABLE 4. PRECISION ESTIMATES BY SOURCE TYPE

	Variance Components		Precision (Percent Opacity)	
Source Type	Reading Error, σ^2	Between Observer, σ_r^2	Single Reading	Method 9 Reading
Coke Battery Stack	12.03	3.75	3.97	2.06
Teeming-Aisle Roof Monitor	12.23	0.84	3.59	1.16
Casthouse	32.45	12.00	6.67	3.65

triangle with one side equal to the square root of the reading-error variance component and the other side equal to the square root of the between-observer variance component. This permits a graphical illustration of the relative effects of the observer and the individual observer's reading error on the precision of the measurement method.

Figure 1 shows the relative effects on the single-observation precision of these sources of variability. Note that the reading error has the largest effect and is almost twice as large for the casthouse as for the other two sources. Figure 2 illustrates the precision of the Method 9 average. Note that the averaging of 24 observations only reduces the effect of reading error and does nothing to the between-observer effect. Thus, the relative importance of the observer effect is much larger for a Method 9 average reading than for a single opacity reading.

SUMMARY

This study has assessed the precision of equivalent-opacity measurements under actual field conditions. It shows that the precision is dependent on the diffusivity of the smoke emission, with the least precision of the measurement corresponding to the source type with the most diffuse smoke emission. This study also shows that the measurement is affected significantly by the observer, and although the individual observer reading error can be reduced by employing Method 9 averaging, the effect of the observer cannot be reduced.

The precision of this measurement method should be taken into account when determining possible violations of applicable opacity standards. Better still, these standards should be stated in such a manner as to explicitly recognize the precision of this measurement method as part of a criteria for compliance determination.

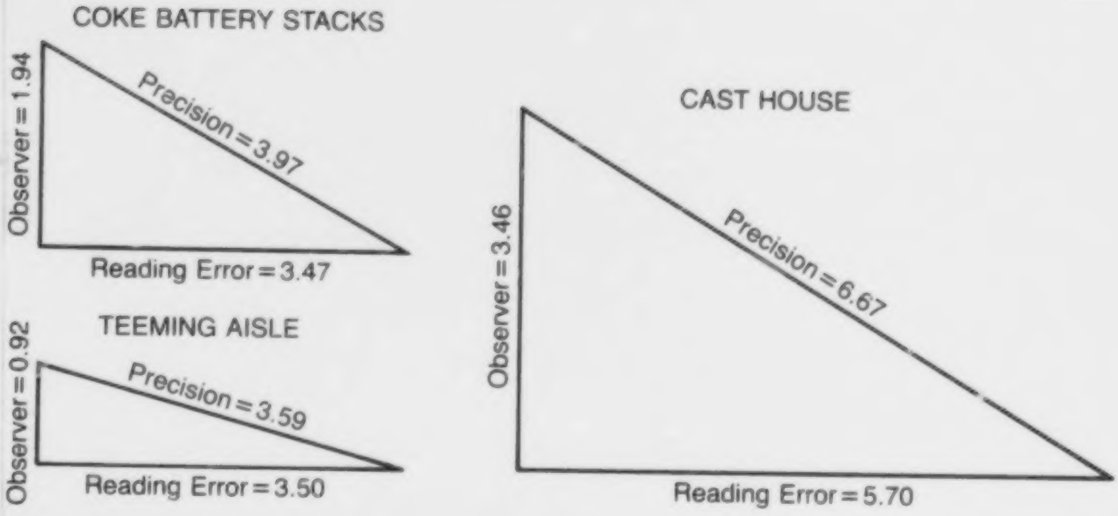

COKE BATTERY STACKS
Observer = 1.94
Precision = 3.97
Reading Error = 3.47
TEEMING AISLE
Observer = 0.92
Precision = 3.59
Reading Error = 3.50
CAST HOUSE
Observer = 3.46
Precision = 6.67
Reading Error = 5.70

Figure 1. Single Observation Precision by Source Type

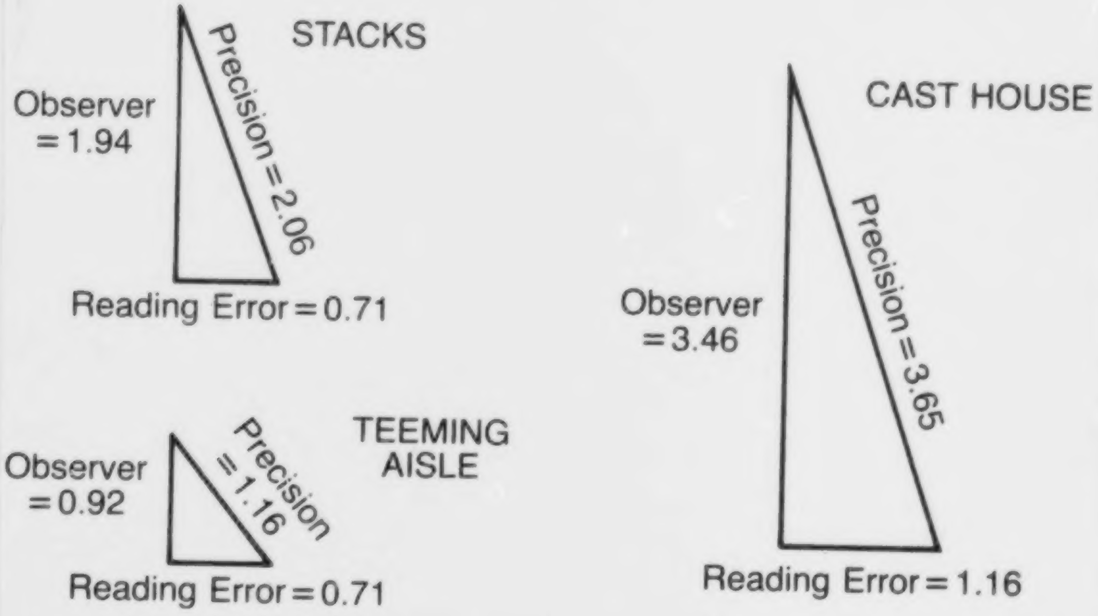

STACKS
Observer = 1.94
Precision = 2.06
Reading Error = 0.71
CAST HOUSE
Observer = 3.46
Precision = 3.65
Reading Error = 1.16
TEEMING AISLE
Observer = 0.92
Precision = 1.16
Reading Error = 0.71

Figure 2. Method 9 Precision by Source Type

REFERENCES

1. A. C. Stern, "History of Air Pollution Legislation in the Central States," *Journal of the Air Pollution Control Association*, Vol. 32, No. 1, January 1982, pp. 44-61.

2. U. S. Environmental Protection Agency, *APTI Course 439 Visible Emissions Evaluation - Student Manual*, National Technical Information Service, PB291861, September 1978.

3. U. S. Environmental Protection Agency, *Evaluation of Visible Emissions - Student Manual*.

4. U. S. Bureau of Mines *Ringelmann Smoke Chart*, U. S. Department of Interior, IC 7718, May 1967.

5. L. S. Chaput: "Federal Standards of Performance for New Stationary Sources of Air Pollution—A Summary of Regulations," *Journal of the Air Pollution Control Association*; Vol. 26; No. 11; Nov. 1976; pp. 1055-60.

6. U. S. EPA Method 9—Visual Determination of the Opacity of Emission from Stationary Sources," *40 CFR Part 60 Appendix A*.

7. R. E. Hague and D. A. Deiss, "Factors Affecting Accuracy in Visual Emissions Evaluation," Paper presented at the 72nd Meeting of the Air Pollution Control Association Cincinnati, Ohio, June 24-29, 1979.

8. A. Weir, Jr., et al.; "Factors Influencing Plume Opacity," *Environmental Science and Technology*, Vol. 10, No. 6, June 1976, pp. 539-44.

9. D. R. Goodwin, "Opacity, A Federal View," *Environmental Science and Technology*, Vol. 11, No. 1, January 1977, pp. 10-11.

10. A. Weir, Jr.; "Clearing the Opacity Issue," *Environmental Science and Technology*, Vol. 11, No. 6, June 1977, pp. 561-63.

The material in this paper is intended for general information only. Any use of this material in relation to any specific application should be based on independent examination and verification of its unrestricted availability for such use, and a determination of suitability for the application by professionally qualified personnel. No license under any United States Steel Corporation patents or other proprietary interest is implied by the publication of this paper. Those making use of or relying upon the material assume all risks and liability arising from such use or reliance.

The work described in this paper was not funded by the U. S. Environmental Protection Agency. The contents do not necessarily reflect the views of the Agency and no official endorsement should be inferred.

THE RELATIONSHIP BETWEEN VISUAL-EMISSION OBSERVATIONS AND CONTINUOUS-EMISSION MONITOR MEASUREMENTS OF COKE-BATTERY STACKS

by: D. E. Splitstone
United States Steel Corporation
Research Laboratory
125 Jamison Lane
Monroeville, Pennsylvania 15146

B. C. Erickson
United States Steel Corporation
Geneva-Pittsburg Works
Provo, Utah 84601

ABSTRACT

Under current regulations, the accepted means for enforcement of opacity-emission standards is the trained, certified observer. The procedure for observer certification requires that a candidate demonstrate the ability to assign opacity readings in 5 percent increments to 25 different black plumes and 25 different white plumes generated by a smoke generator. The reference standard for this demonstration is a smoke meter or continuous-emission monitor (CEM) within the stack of the smoke generator. Therefore, it might be expected that a good and consistent relationship would be found between visual-emission observations (VEO) and CEM readings in the field.

However, in the present study extensive analysis of data collected on coke-oven-battery stacks equipped with CEM's revealed that, although a correlation exists between VEO and CEM readings in the general sense that VEO readings tend to increase or decrease when CEM readings increase or decrease, no consistent relationship exists for predicting VEO readings from CEM readings. This is particularly, and most importantly, the case for high CEM readings. Therefore, the CEM readings cannot be used as a surrogate measure of visual-emission opacity for coke-oven-battery stacks.

BACKGROUND

A program designed to gather data for investigating the existence of a correlation between visual-emission-observation (VEO) measurements and continuous-emissions-monitor (CEM) readings from coke-battery stacks at U. S. Steel's Geneva Works in Provo, Utah, was carried out during June 1981. This program was initiated at the request of the Utah Department of Health (UDH) and conducted on Geneva Works coke-oven-battery stacks No. 2 and 4. The protocol governing the data-gathering program called for the simultaneous observation of equivalent opacity on the two stacks by four observers at 15-second intervals during the data-gathering period.(1)*

---

* See References.

Two of the four observers were from UDH and two from U. S. Steel. Concurrent readings of the CEM output for each stack were also recorded. Coordination of the observation timing was accomplished by radio communication.

During the actual conduct of the program, there were four separate observational periods. The first two of these were on June 3, 1981, beginning at 2:20 p.m. and 3:43 p.m., respectively. All four observers were employed during these first two periods, which had a duration of one hour. The third period was also conducted on June 3, 1981, and began at 4:50 p.m. and lasted for 24 minutes. Only the two U. S. Steel observers were employed during this third period. The fourth period of observation was conducted on June 12, 1981, beginning at 2:50 p.m. and lasting 24 minutes. Only the two U. S. Steel observers were employed during this last period. The observational periods will be referred to as test runs in the remainder of the text so as to avoid confusion with the 15-second period in which observations were taken.

VARIABILITY DUE TO OBSERVERS

The data collection of the equivalent opacity readings employed multiple observers reading opacities for each stack at the same time from essentially the same position with respect to the stacks. Prior to investigation of the correlation between VEO and CEM measurements, an analysis of the VEO data was performed to determine the effect of the observer, if any, and the precision associated with the VEO measurements.2) Only data from the first two tests on each stack were employed in these analyses.

The analyses of variance for stacks No. 2 and 4 are presented in the attached Table 1. These analyses indicate that the choice of observer introduces a highly significant component of variability into the data. To minimize this component of variation in the investigation of the correlation between VEO and CEM readings, the mean VEO reading for each 15-second observation period is used for the remainder of the analysis. When less than two observers recorded a reading during any 15-second period, because of obscured vision, that period was treated as one with missing data.

CORRELATION BETWEEN VEO AND CEM READINGS

The mean equivalent opacity for each observational period and the CEM reading for each period for the first two test runs on stack No. 4 are presented as a function of time in Figure 1. Similar behavior is exhibited by the mean equivalent opacities and CEM readings for all test runs regardless of the stack. Inspection of these figures reveals that changes in the CEM reading with time are generally reflected by changes in the mean VEO readings. Note that there are few high observations with the majority of the observations falling in the low opacity range. Very careful inspection

TABLE 1. ANALYSIS OF VARIANCE
Coke Battery Stack No. 2

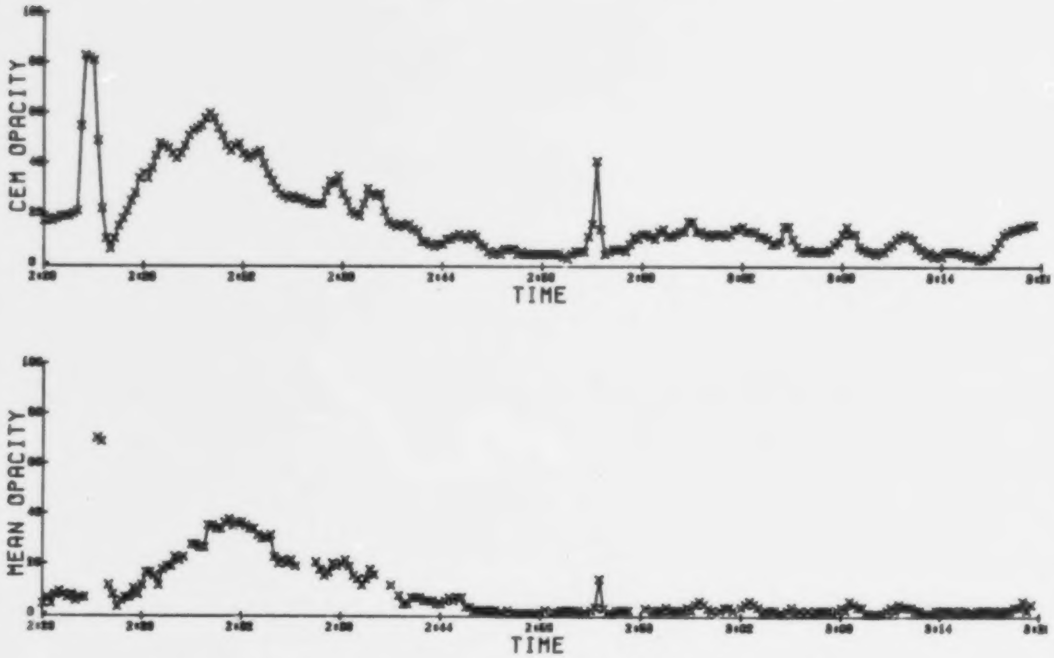
Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F-Statistic
Period Effect	474	185505.08	391.36	
Observer Effect	3	5915.19	1971.73	165.56*
Reading Error	1324	15768.14	11.91	
	1801	207188.41		

Analysis of Variance
Coke Battery Stack No. 4

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F-Statistic
Period Effect	461	153536.80	333.05	
Observer Effect	3	4648.29	1549.43	127.45*
Reading Error	1355	16472.54	12.16	
	1819	174657.63		

*Significant at the 0.001 level.

STACK 4 RUN 1 - CEM AND MEAN VISUAL OPACITY - 3 JUNE 1981



STACK 4 RUN 2 - CEM AND MEAN VISUAL OPACITY - 3 JUNE 1981

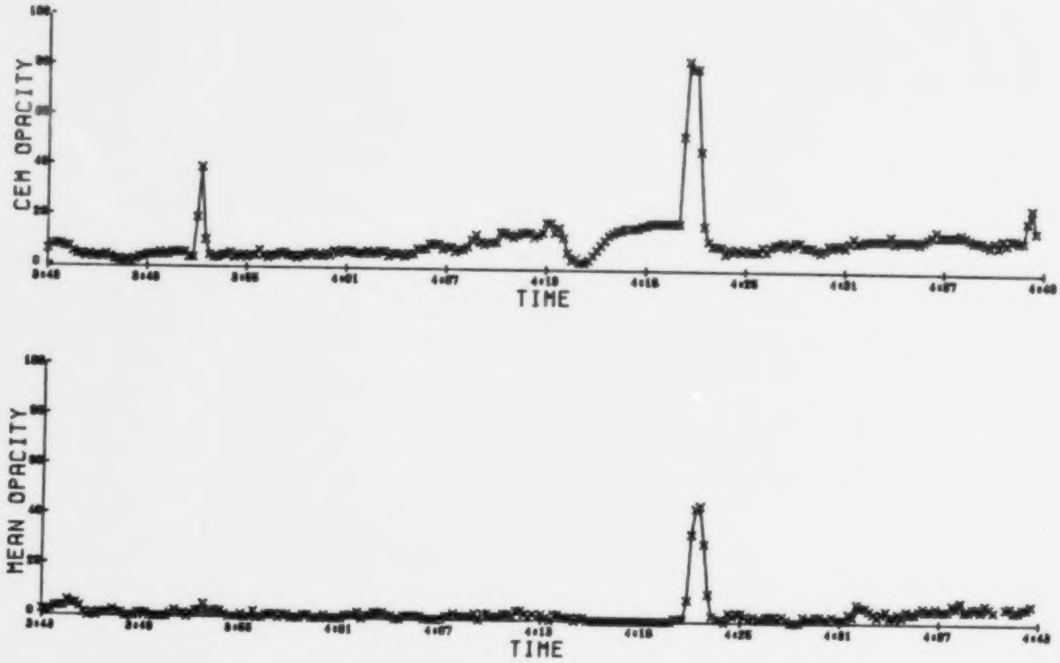


Figure 1.

(see Figure 2) reveals that a change in the VEO reading is delayed in time from a change in the CEM reading. Thus, changes in VEO readings tend to lag changes in CEM readings. This lag is a logical result of the CEM's being located some distance below the top of their respective stacks.

The existence of this lag was also anticipated by the UDH and U. S. Steel in the test protocol. The final agreement between UDH and U. S. Steel on the test protocol called for investigation of the correlation between VEO and CEM readings to be carried out by pairing a VEO reading with the CEM reading of the prior 15-second period.

FORMALIZATION OF THE CORRELATION VIA LINEAR REGRESSION

A possible means of formalizing the apparent correlation between mean VEO and CEM readings is to employ the technique of simple linear regression, that is to fit the relationship

$$\text{Mean VEO} = A + B \times \text{CEM} + \text{error}$$

The constants A and B are estimated from the data by linear least squares and the magnitude of the error is estimated from the residuals or differences between predicted and observed mean VEO readings.

The mean VEO readings lagged by one 15-second time period, were regressed on the CEM readings for each stack. A necessary condition for the linear least-squares estimates of A and B to be unbiased and "best" in the statistical sense of minimum variance is that the errors, or residuals, be uncorrelated.3) To test for the existence of this condition, the autocorrelation function of the residuals was calculated for each stack. Tables 2 and 3 give the values of the residual autocorrelation function for stacks No. 4 and 2, respectively. In estimating the autocorrelation functions, periods having missing mean VEO readings were assigned a residual of zero.

The autocorrelations presented in Tables 2 and 3 are significantly different from zero for lags of 15 and 30 seconds, and there is also evidence of nonzero autocorrelations for lags as large as 195 seconds. Thus, the residuals for each stack are correlated and, therefore, the estimates A and B of the linear relationship are neither unbiased nor "best" estimates of the true parameters.

Histograms of the residuals for stacks No. 4 and 2 are presented in Figure 3. To the naive data analyst, who ignores the implications of the residual autocorrelation, these figures may suggest the happy set of circumstances that most of the residuals appear to be clustered quite close to zero with only a few extremes. Consideration, however, must be given to the time of occurrence of these few extreme residuals as illustrated in Figure 4. Note that the few extreme residuals occur in concert with the few peak mean VEO readings, and it is precisely these peaks for which good predictability is desirable.

TABLE 2. AUTOCORRELATION FUNCTION OF LINEAR REGRESSION RESIDUALS STACK NO. 4

Lag (seconds)	15	30	45	60	75	90	105	120	135	150
Correlation	0.70	0.45	0.23	0.07	0.06	0.12	0.17	0.19	0.18	0.17
Std. Error	0.04	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.07
Lag (seconds)	165	180	195	210	225	240	255	270	285	300
Correlation	0.17	0.15	0.14	0.11	0.10	0.10	0.09	0.09	0.07	0.04
Std. Error	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07

TABLE 3. AUTOCORRELATION FUNCTION Of LINEAR REGRESSION RESIDUALS STACK NO. 2

Lag (seconds)	15	30	45	60	75	90	105	120	135	150
Correlation	0.70	0.26	0.04	0.05	0.09	0.10	0.11	0.12	0.14	0.15
Std. Error	0.04	0.05	0.06	0.06	0 06	0.06	0.06	0.06	0.06	0.06
Lag (seconds)	165	180	195	210	225	240	255	270	285	300
Correlation	0.15	0.13	0.12	0.10	0.09	0.08	0.06	0.05	0.02	0.03
Std. Error	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06

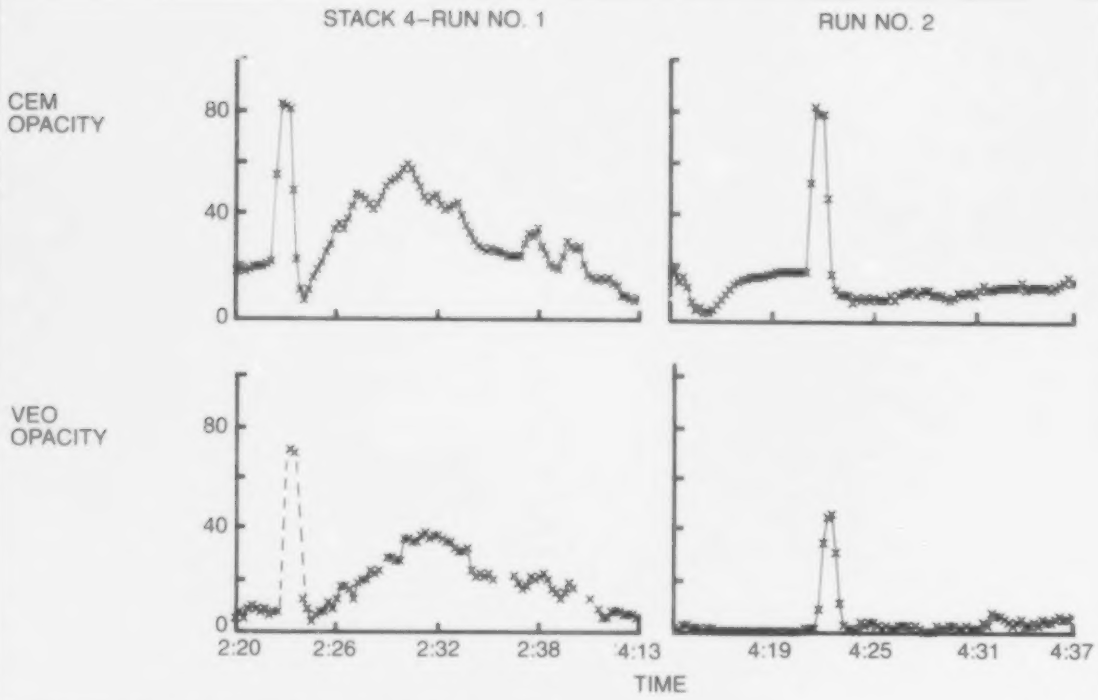


Figure 2. CEM and Mean Visual Opacity

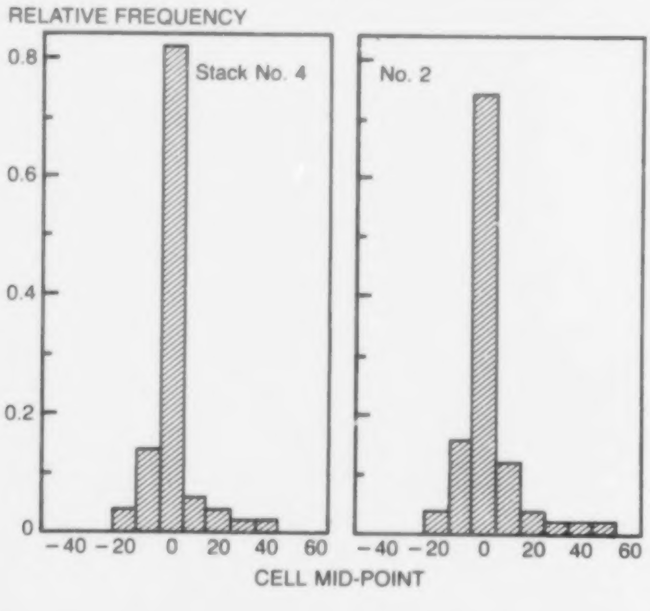


Figure 3. Histograms of Linear Regression Residuals

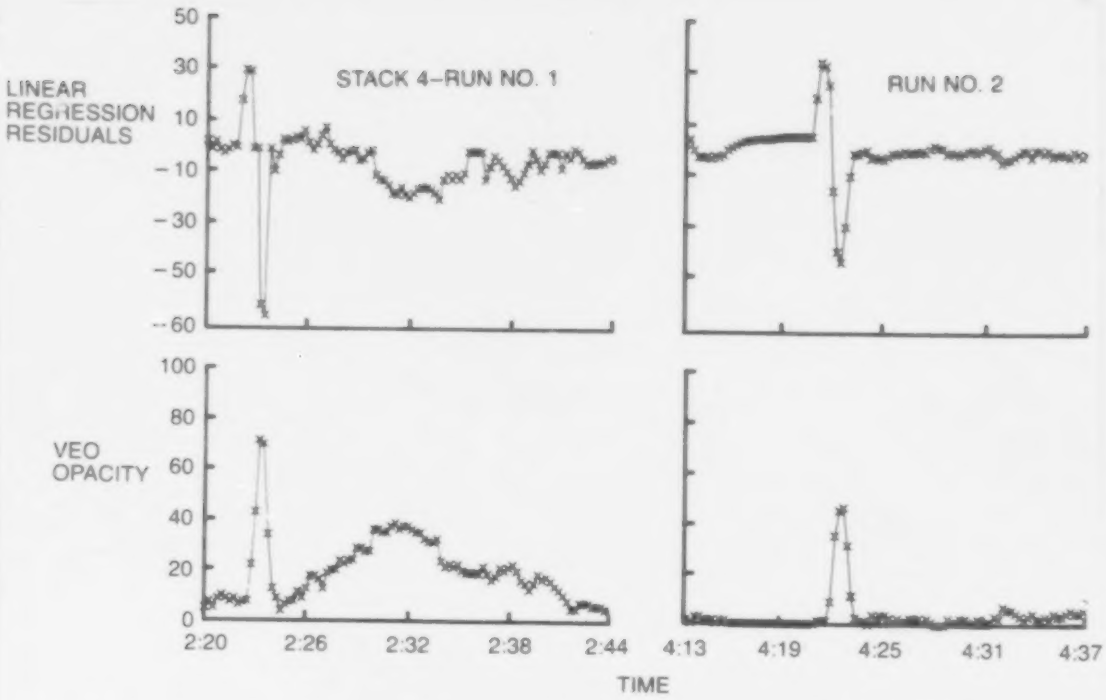


Figure 4. Linear Regression Residuals and Mean Opacity Versus Time

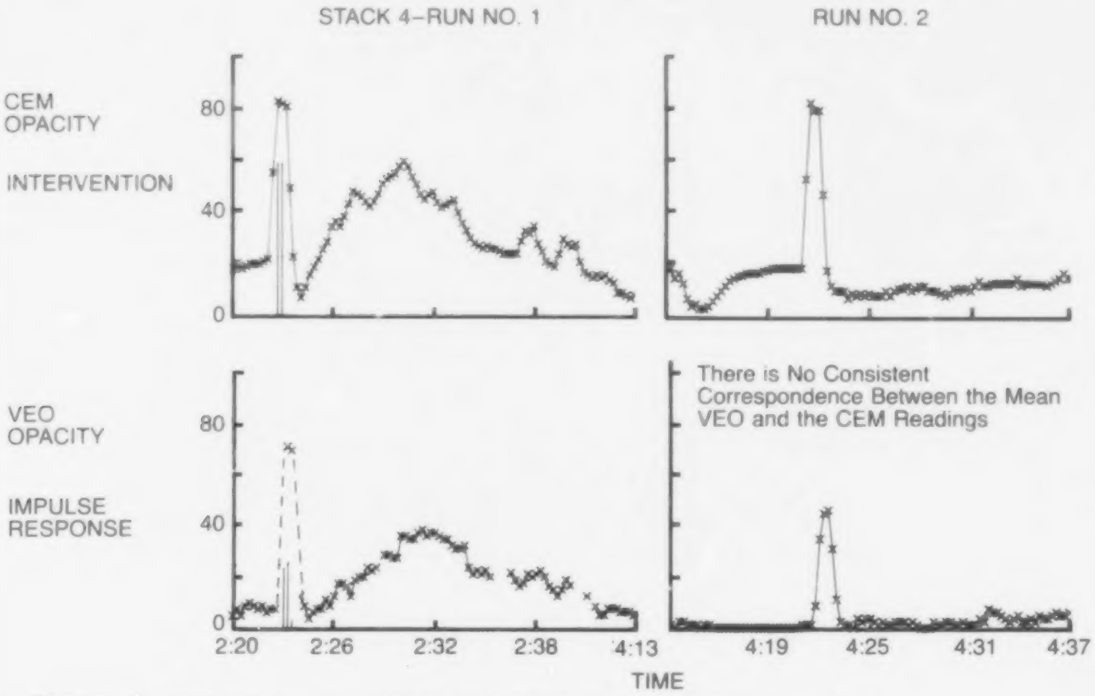


Figure 5. Use of Intervention and Estimated Impulse Response

Thus, the use of linear-regression techniques to describe the correlation between the mean VEO readings and the CEM readings is totally inadequate.

FORMALIZATION OF THE CORRELATION VIA TRANSFER-FUNCTION MODELS

A class of mathematical models capable of formalizing the correlation between mean VEO readings and CEM readings in the presence of the autocorrelation between successive readings is provided by the transfer-function models of Box and Jenkins.[4-7] In addition, through the use of binary series, the time discontinuities among test runs on the two stacks may be accounted for and overcome. In this study, a binary series, or "intervention," was also required to adequately model the change in VEO response to peaks in the CEM series.[6,7]

The identification, fitting, and checking of a transfer-function model is a time-consuming procedure. The details of the identification, fitting, and checking of the models presented here will not be discussed, except in very broad terms. Those interested in the detailed steps involved are referred to References 4 through 7.

The structure of the autocorrelation functions for the VEO and CEM readings for both stacks indicates that a VEO reading and a CEM reading are related to their respective prior close neighbors in time. This low-order autoregressive behavior suggests that the series for each test run may be combined into one series for each stack by employing binary series to correct for the discontinuity in time. These binary series have the value of zero (0) everywhere but for the first observation of the next test run, where it takes on the value of one (1). The response to these impulse functions was estimated to be rapidly damped exponential weights, which provide a smooth transition between test runs No. 1 and 2, 2 and 3, and 3 and 4. Since these corrections for time discontinuity add nothing to the information regarding the relationship between VEO readings and CEM readings, they will not be discussed further. Their existence, however, will be acknowledged in the mathematical expression of the models estimated for stacks No. 4 and 2.

Because the transfer-function model identification process indicates the magnitude of the time delay, or lag, between the response series (VEO reading) and input series (CEM series), the VEO and CEM readings were paired in real time for this analysis. That is, there was no 15-second delay built into the data set prior to the analysis, as was the case for application of linear regression.

In the course of estimating and checking the models describing the VEO-CEM correlation for both stacks No. 4 and 2, it was apparent that the responses of the mean VEO to peaks in CEM readings lacked consistency. This is best illustrated by two peak periods in CEM readings observed on stack No. 4, as shown in the following table:

Time June 3, 1982	Mean VEO Reading	CEM Reading
2:22:15	6.25	22
2:22:30	7.50	56
2:22:45	7.50	84
2:23:00	-	83
2:23:15	50.00	82
2:23:30	62.50	50
2:23:45	70.00	23
2:24:00	-	11
2:24:15	6.67	7
4:21:15	1.25	19
4:21:30	1.25	54
4:21:45	1.25	84
4:22:00	8.75	81
4:22:15	35.00	81
4:22:30	45.00	48
4:22:45	46.25	18
4:23:00	31.25	12
4:23:15	11.25	10

Here are two time periods having essentially the same sequence of CEM readings, but different mean VEO responses. These are also periods of peak CEM readings. Similar behavior is exhibited also for stack No. 2. It is important to note that this behavior occurs for the mean VEO response to peaks in the CEM readings. In order to build models for stacks No. 4 and 2 that adequately described what had been observed, it was necessary to introduce an intervention series to account for the different mean VEO readings corresponding to similar CEM reading peaks. Like those series used to smooth the transition between runs, this intervention series is a sequence of zeros and ones. This series takes on a value of one when required to improve the model at a point of major increase in the CEM reading. The use of these intervention series, along with their estimated impulse-response functions, is illustrated in Figure 5 for the sequence of observations on stack No. 4 discussed above.

Note that as illustrated in Figure 5, interventions are not required for every peak in the CEM readings. Indeed the use of these interventions is rare. Because the introduction of these interventions is required and the estimated impulse response weights are statistically significant, the conclusion can be drawn that there is no consistent correspondence between the mean VEO and CEM readings, particularly and most importantly, when the CEM readings peak.

The transfer-function models describing the relationship between mean VEO readings and CEM readings for stacks No. 4 and 2 can be mathematically represented using the following notation:

VEO_t = mean VEO reading at time t

CEM_t = CEM reading at time t

$Y_t^{(I)}$ = response at time t due to an intervention, I

$Y_t^{(T_i)}$ = response at time t due to the transition T_i between test runs, i = 1,2,3.

N_t = the modelable noise defined as the difference between the observed mean VEO and the value of the transfer function, and

a_t = random shocks to the system.

The model for stack No. 4 is given by

$$VEO_t = -\ 3.004 + 0.1006\ CEM_{t-1} + 0.2705\ CEM_{t-2} + 0.2012\ CEM_{t-3} + 0.0447\ CEM_{t-4} + Y_t^{(T_1)} + Y_t^{(T_2)} + Y_t^{(T_3)} + N_t$$

where

$$N_t = 0.8202\ N_{t-1} + 0.1586\ N_{t-15} + 0.1301\ N_{t-16} + a_t$$

$$Y_t^{(I)} = 0.1093\ Y_{t-1}^{(I)} + 23.46\ I_{t-4}$$

$$Y_t^{(T_1)} = 0.6698\ Y_{t-1}^{(T_1)} - 3.549\ T_1$$

$$Y_t^{(T_2)} = 0.6129\ Y_{t-1}^{(T_2)} - 9.996\ T_2$$

$$Y_t^{(T_3)} = 0.9949\ Y_{t-1}^{(T_3)} - 5.791\ T_3$$

A schematic diagram of this model aside from the transition functions is given as Figure 6. Note that this model indicates that the mean VEO is the weighted average of a full minute of prior CEM readings.

The estimated model for stack No. 2 is then given by

$$VEO_t = -2.7072 + 0.2241\ CEM_{t-1} + 0.3091\ CEM_{t-2} + Y_t^{(I)} + Y_t^{(T_1)} + Y_t^{(T_2)} + Y_t^{(T_3)} + N_t$$

where

$$N_t = 0.9884\ N_{t-1} + a_t - 0.3916\ a_{t-1} - 0.2143\ a_{t-2} - 0.1735\ a_{t6}$$

SCHEMATIC OF TRANSFER FUNCTION MODEL FOR STACK 4

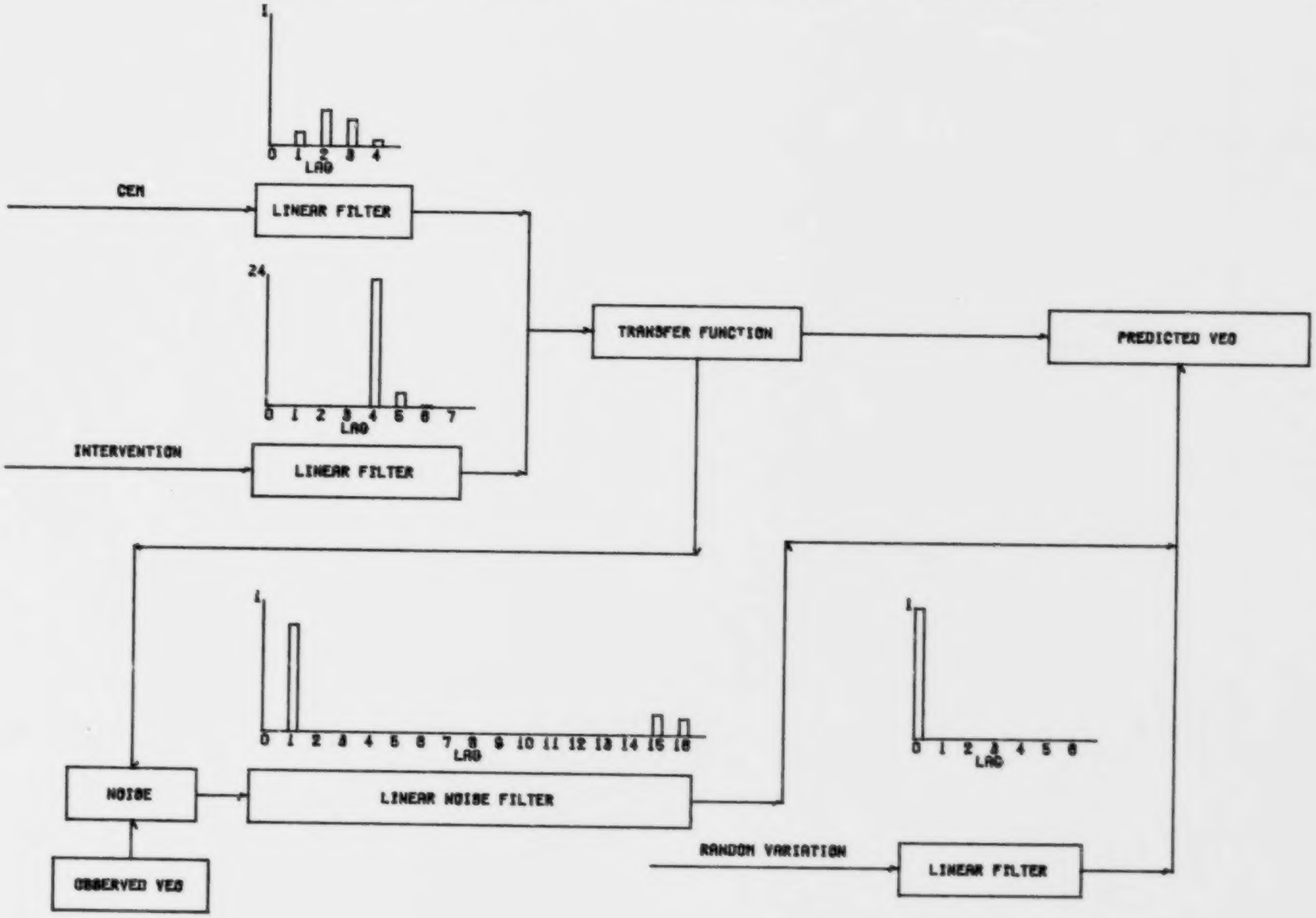

1
0 1 2 3 4
LAG
CEM
LINEAR FILTER
24
0 1 2 3 4 5 6 7
LAG
INTERVENTION
LINEAR FILTER
TRANSFER FUNCTION
PREDICTED VEO
1
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
LAG
NOISE
LINEAR NOISE FILTER
OBSERVED VEO
1
0 1 2 3 4 5 6
LAG
RANDOM VARIATION
LINEAR FILTER

Figure 6.

$$Y_t^{(I)} = 0.5657\ Y_{t-1}^{(I)} + 18.56\ I_{t-2}$$

$$Y_t^{(T_1)} = 0.5014\ Y_{t-1}^{(T_1)} - 35.20\ T_1$$

$$Y_t^{(T_2)} = 0.3885\ Y_{t-1}^{(T_2)} + 6.458\ T_2$$

$$Y_t^{(T_3)} = 0.5611\ Y_{t-1}^{(T_3)} + 19.03\ T_3$$

This model, aside from the transition component, is represented schematically in Figure 7. This model indicates that the mean VEO is the weighted average of CEM readings 15 and 30 seconds prior to the time of observation, plus the intervention and transition functions and noise.

The I and the T_i (i = 1, 2, 3) in the above formulation represent sequences of zeros and ones. The interpretation of the expressions involving $Y_t^{(I)}$ or $Y_t^{(T_i)}$ can therefore be described simply by taking as an example the expression

$$Y_t^{(I)} = 0.5657\ Y_{t-1}^{(I)} + 18.56\ I_{t-2}$$

given for stack No. 2. The value of $Y_t^{(I)}$ is zero so long as the series I is zero. When I takes on a value of one, the predicted mean VEO two time periods (30 seconds) later is increased by 18.56 percent opacity. Since, in most cases, the occurrence of one in the series I is isolated, the impact of this addition decays exponentialy with time, as follows:

Time	I_t	$Y_t^{(I)}$
t-3	0	0
t-2	1	0
t-1	0	0
t	0	18.56
t+1	0	10.50
t+2	0	5.94
t+3	0	3.36
t+4	0	1.94

The ability of these models to track the observed mean VEO readings is illustrated in Figure 8. The residuals or differences between predicted and observed mean VEO readings for the transfer function models are illustrated in Figure 9, for stack No. 4. Comparison of this figure with Figure 4 for linear regression illustrates the far superior predictability of the transfer-function models.

SCHEMATIC OF TRANSFER FUNCTION MODEL FOR STACK 2

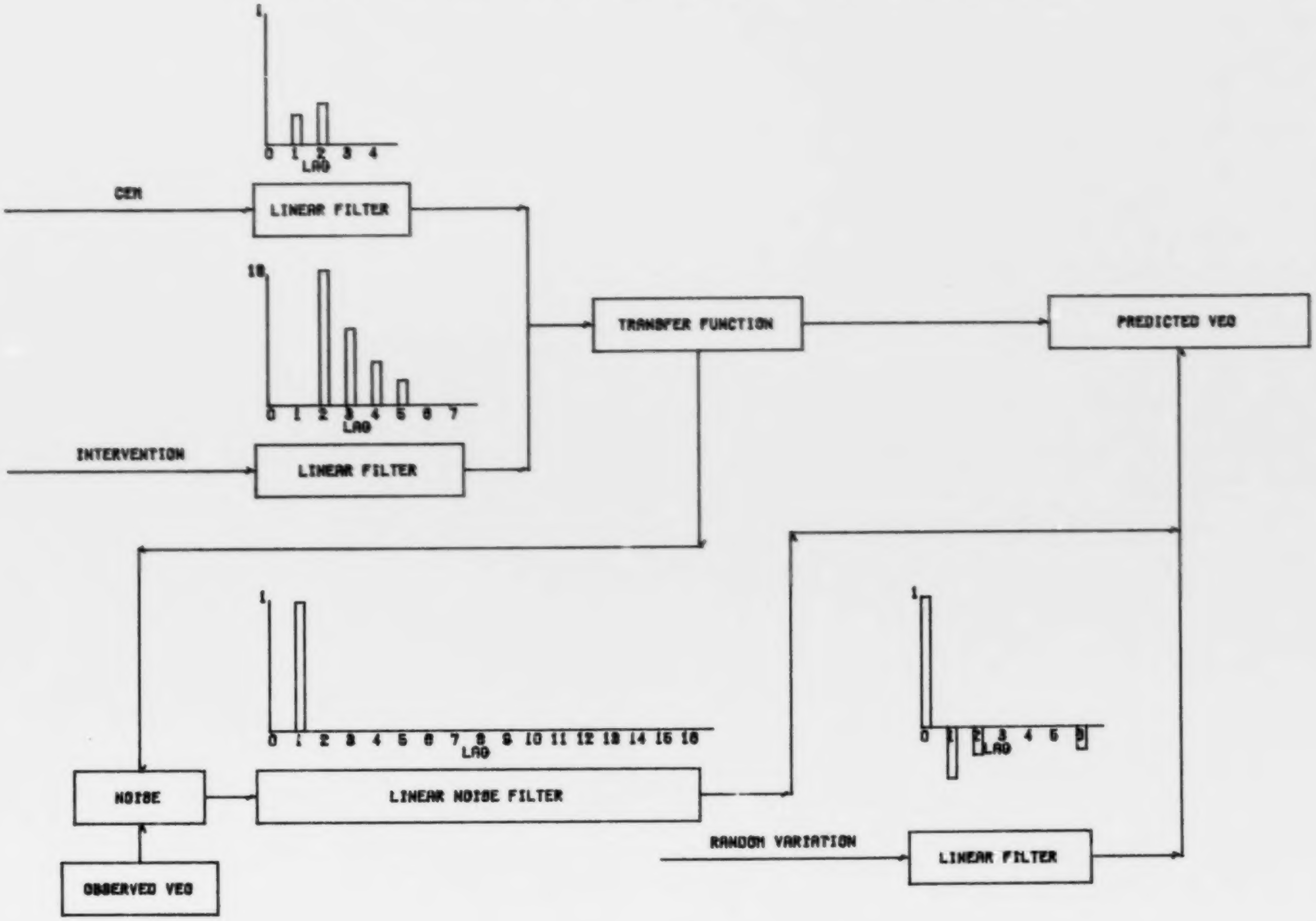

1
0 1 2 3 4
LAG
CEM
LINEAR FILTER
18
0 1 2 3 4 5 6 7
LAG
INTERVENTION
LINEAR FILTER
TRANSFER FUNCTION
PREDICTED VEO
1
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
LAG
NOISE
LINEAR NOISE FILTER
OBSERVED VEO
1
0 1 2 3 4 5 6
LAG
RANDOM VARIATION
LINEAR FILTER

Figure 7.

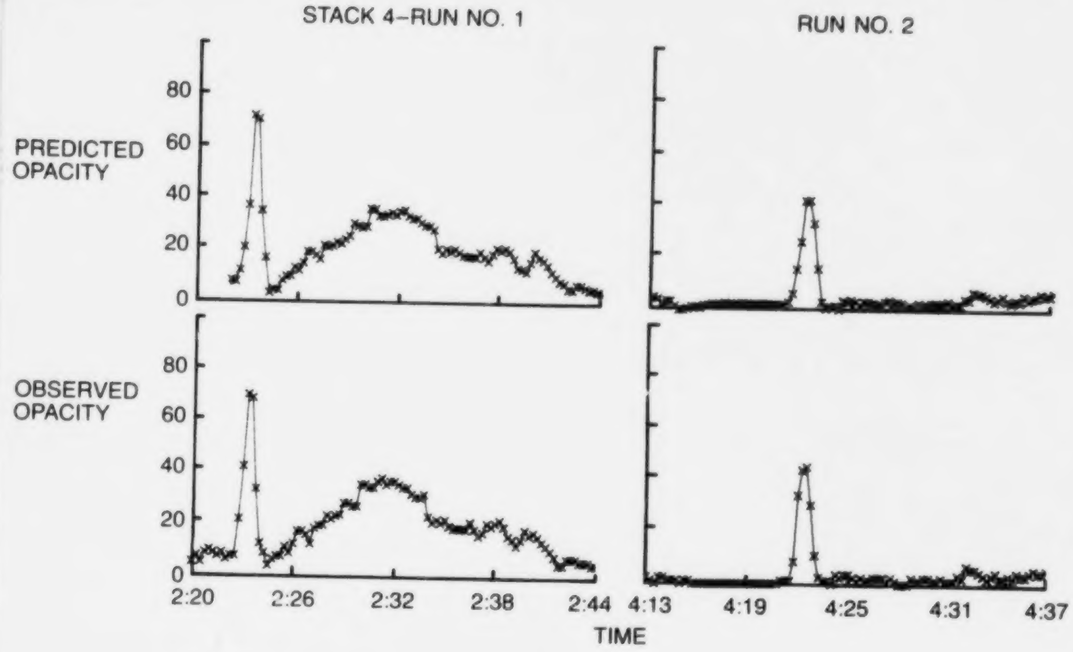


Figure 8. Predicted and Observed Mean Opacity Versus Time

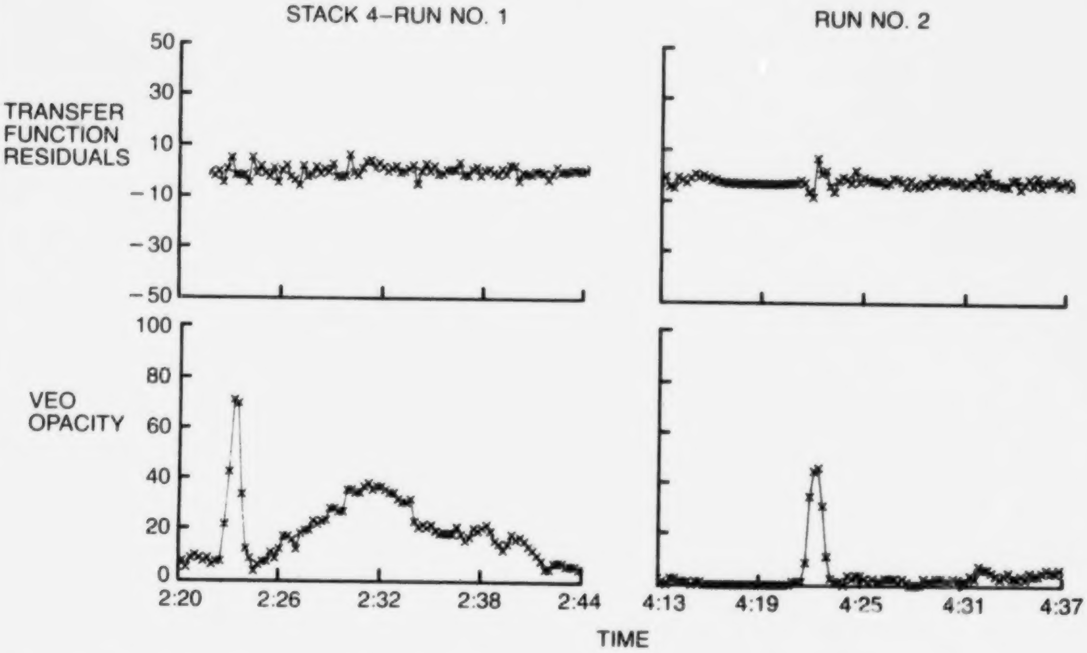


Figure 9. Transfer Function Model Residuals and Mean Opacity Versus Time

CONCLUSION

The worth of any statistical or mathematical model is determined by how well it predicts what has been observed. All measures of the "goodness" of prediction are functions of the residuals, which are the differences between model prediction and the observation.

The use of linear regression to formalize a relationship between mean VEO readings and CEM readings is not appropriate because the residuals exhibit a pattern in time indicating model inadequacy. Further, the maximum residuals from the regression line correspond with the occurrence of high values or peaks in the CEM readings, and it is precisely these peaks for which good prediction is required.

Statistical techniques appropriate for use when observations are related in time were applied. The transfer-function models subsequently developed describe the relationship between mean VEO readings and CEM readings for the data taken during June 1981 very well. However, the models developed for stacks No. 4 and 2 differ in form, implying that the relationship is different for different stacks. Further, each model requires the inclusion of an adjustment, or intervention, to adequately predict the occurrence of some peak mean VEO readings from peak CEM readings. These interventions are not required for every peak in the CEM readings, nor can the CEM readings be used to predict when they are required. Thus, there is no consistent correspondence between the mean VEO and CEM readings, particularly and most importantly, when the CEM readings peak.

Therefore, although a correlation between mean VEO readings and CEM readings exists in the general sense that VEO readings tend to increase or decrease when CEM readings increase or decrease, no consistent relationship for predicting VEO readings from CEM readings exists. This is particularly the case for high CEM readings. The CEM readings, then, cannot be used to predict visual-emission opacity for the Geneva battery stacks.

REFERENCES

1. U. S. Steel Geneva Works, "Protocol for Coke Plant Continuous Emission Monitor Test for Correlation with Method 9 Observations," June 1, 1981.

2. D. E. Splitstone and J. Y. Lin, "The Precision of Visual Emission Observations Within an Integrated Steel Works," to be presented at AISI-EPA Symposium on Pollution Abatement in the Iron and Steel Industry, November 16-18, 1982.

3. F. A. Graybill, An Introduction to Linear Statistical Models, Vol. I, McGraw-Hill Book Co., Inc., 1961, p. 115.

4. G. E. P. Box and G. M. Jenkins, Time Series Analysis: Forecasting and Control, Holden-Day, 1976.

5. D. J. Pack, "Revealing Time Series Interrelationships," Decision Sciences, No. 8, April 1977, p. 377-402.

6. G. E. P. Box and G. E. Tiao, "Intervention Analysis With Applications to Economic and Environmental Problems," Journal of the American Statistical Association, Vol. 70, No. 349, March 1975.

7. R. M. Helmer and J. K. Johansson, "An Exposition of the Box-Jenkins Transfer Function Analysis With an Application to Advertising-Sales Relationship," Journal of Marketing Research, Vol. XIV, March 1972, p. 227-239.

The material in this paper is intended for general information only. Any use of this material in relation to any specific application should be based on independent examination and verification of its unrestricted availability for such use, and a determination of suitability for the application by professionally qualified personnel. No license under any United States Steel Corporation patents or other proprietary interest is implied by the publication of this paper. Those making use of or relying upon the material assume all risks and liability arising from such use or reliance.

This paper has been reviewed in accordance with the U.S. Environmental Protection Agency's peer and administrative review policies and approved for presentation and publication.

BENZENE EMISSIONS SOURCES AND EMISSIONS CONTROL AT COKE BY-PRODUCT PLANTS

by: Leslie L. Beck
U.S. Environmental Protection Agency
Research Triangle Park, NC

C. Clark Allen and David W. Coy
Research Triangle Institute
Research Triangle Park, NC

ABSTRACT

Benzene emissions are of concern at coke oven by-product plants due to benzene's carcinogenic potential. Major emission sources in by-product recovery plants are open or partially closed process vessels. This paper describes the emission factors, the relative significance of specific process sources, and air pollution control technology to reduce these benzene emissions.

The purpose of this paper is to present benzene emissions data and emission control technology for coke oven by-product plants. The information was compiled by the Research Triangle Institute (RTI) as part of a contract with the United States Environmental Protection Agency (EPA).

Coke is one of the basic materials used in blast furnaces for the conversion of iron ore into iron. The conversion of coal by destructive distillation to coke is performed in the coke oven batteries. In the coke by-product plant, the various chemicals evolving from the coal during the coking process are separated and recovered. The cleaned coke oven gas can then be used as fuel to make more coke. Excess coke gas is used as fuel for other plant operations. Coke by-products include coal tar, ammonia, naphthalene, crude or light oils, benzene, and benzene mixtures.

The coke by-product recovery industry is characterized by a wide diversity of processes at about 55 plant locations in the United States. Although many plants differ in terms of processes or final products, Figure 1 indicates the basic separation and recovery processes that are similar for many of the by-product plants.

When the coke oven gas leaves the coke oven, initial condensation of the tar contained in the gas occurs by direct contact with flushing liquor in the collecting main. About 80 percent of the tar is separated from the gas in the collecting main and is flushed to a tar decanter. Flushing liquor that separates from the tar in the tar decanter is recirculated to the collecting main. Tar from the tar decanter may be forwarded to tar dewatering vessels prior to storage in vented storage tanks.

Most of the remaining tar is condensed in a primary cooler. The gas is again cooled by a final cooler, and condensed water and naphthalene are removed. Once the naphthalene is removed, it is melted, thermally dried, and stored in heated tanks. After the final coolers, the gas passes through light-oil scrubbers where the light oil, a by-product fraction containing 60-80 percent benzene, is removed by absorption in an organic scrubbing liquor called wash oil. With further distillation, benzene mixtures or pure benzene may be produced and held in vented storage tanks pending use or sale.

Benzene, which was listed by the EPA as a hazardous air pollutant in June of 1977, is a major pollutant emitted from by-product recovery processes. Benzene emissions are generally fugitive in nature and are emitted in varying amounts from numerous sources at a typical plant. Industry-wide benzene emissions are estimated at 30,000 Mg/year. Because benzene has only recently been recognized as a hazardous air pollutant, the industry is generally uncontrolled. Emissions of other organic compounds have also been measured at by-product plants. The total organic compound emissions are estimated to be approximately six times greater than the benzene emissions.

After surveying the literature, State and local control agencies and private industry sources, we found that very little emissions data for coke

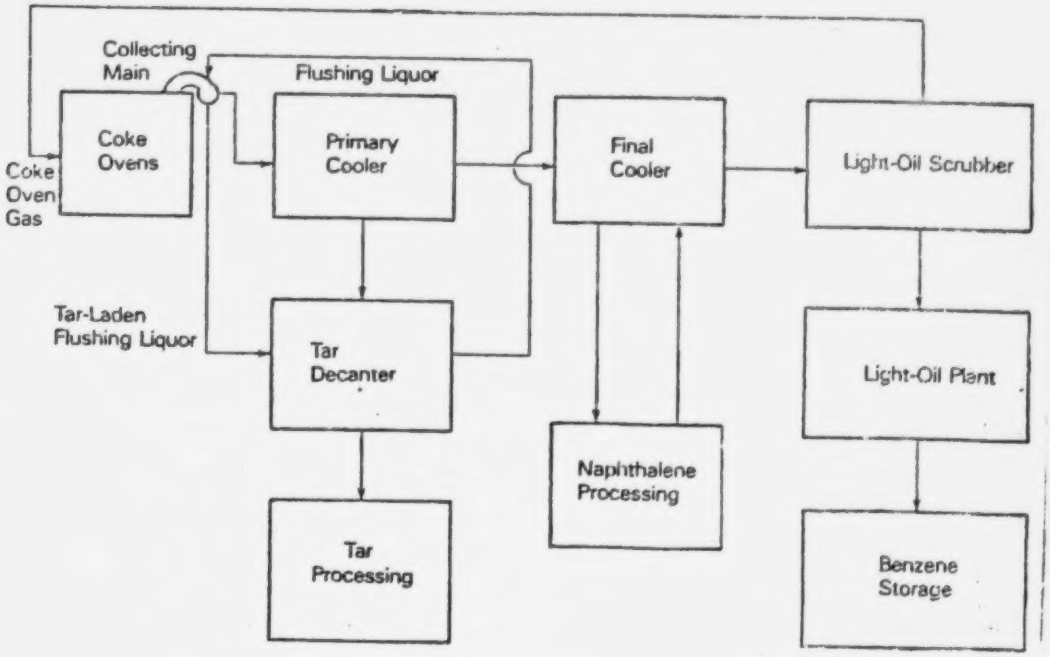

Collecting Main
Flushing Liquor
Coke Ovens
Coke Oven Gas
Primary Cooler
Final Cooler
Light-Oil Scrubber
Tar-Laden Flushing Liquor
Tar Decanter
Light-Oil Plant
Naphthalene Processing
Tar Processing
Benzene Storage

Figure 1. Coke By-Product Recovery Plant

by-product recovery plants were available. Consequently, EPA conducted a testing program at seven representative plants to determine the most significant sources of benzene emissions. Due to the number of potential sources of benzene emissions from these plants, the major purpose of the testing program was limited to the identification of the largest sources of benzene emissions.

Sampling Techniques and Methods

Emissions from leaks in process equipment such as pumps and valves were estimated by screening these potential sources at three by-product plants. The method used involves using a leak detector such as an organic vapor analyzer which uses a flame ionization detector to sense the presence of organic vapors at a source.

Based upon the screening results, the leaking process equipment was identified and the benzene emissions were then measured by enclosing the sources and measuring the air flow through the enclosure and the benzene concentrations leaving the enclosure. Since the benzene emissions did not significantly differ from previous emissions for similar equipment in the petroleum refining industry, the ultimate emission estimate was then based on the estimate of the number of potential sources at a plant and the emission factors obtained from the petroleum refining industry.

Because the emissions from some sources such as tar decanters and dewatering tanks contain large amounts of condensable materials such as naphthalene and tars, existing measurment methods such as EPA Method 110 had to be modified by installing traps and instituting rigorous sample clean up procedures to assure that all the benzene collected during the sampling period was measured. Sources such as cooling towers presented additional problems such as the necessity to traverse large areas to determine gas exit velocities. This was accomplished by using a vane anemometer with direct electronic readout attached to a long rigid rod. Velocity measurements were then taken at equal area intervals across the top of the fan shroud.

The most challenging emission measurement obstacle was determining emissions from open areas with extremely low emission velocities, such as open sumps. An entirely new method was developed by EPA's emission measurement contractor, Scott Environmental Technology, Inc., to accommodate this situation. Briefly, the method involves the release of a known amount of a tracer gas into the emission plume.

The tracer gas method is a practical procedure for quantifying mass emissions of volatile organics from sources which are essentially open to the atmosphere without disturbing flow, dispersion patterns or the source operation. This method utilizes the release of a tracer gas directly over the source of interest; the tracer gas will then follow the same dispersion patterns as the emissions from the source. The mass of tracer released over the sampling period is known and the mass to mass ratio of the benzene to the tracer gas in the collected samples is determined by gas chromatography. The emission rate of the benzene can be calculated with this information.

This method is based on the principle that the chosen tracer gas will be dispersed in the same manner as the benzene which is emitted from the source. The tracer gas chosen for this project was isobutane because it was not present in the sources to be tested and it could readily be separated from other source trace components by the same chromatograph column used for benzene. In addition, isobutane is a non-toxic gas that can be readily dispensed from a pressurized cylinder at a uniform, measured rate.

The program for a sampling run generally involved the collection of triplicate downwind samples and a single point upwind sample. Prior to testing, grab samples were collected in glass flasks and analyzed to determine the benzene concentration in the vicinity of the source to be tested. This information was correlated with wind speed and direction to choose the exact sampler locations. In the ideal case downwind samplers would be equidistant from the source and along approximately a 30° arc.

The tracer gas dispersion apparatus was positioned over the source to be tested as near as possible to the actual emissions. Ideally the dispersion tube or support member spanned the source of the emissions at its center. After being collected the tracer gas samples were immediately transported to the gas chromatograph and analyzed. The elapsed time between sample collection and analysis never exceeded one hour.

To check the validity of the tracer gas method, a series of experiments was run in which known amounts of benzene and isobutane were released simultaneously, and the ratio of the two was checked against the downwind sample concentration ratio.

Two methods were tried for releasing benzene: Direct evaporation, and evaporation through a heated bubbler. Both methods proved adequate for experimental determinations. When evaporation was used to release benzene, a stainless steel pan was employed to contain the benzene. During an experimental determination known quantities of benzene were added to the pan at intervals frequent enough to maintain a constant surface area of benzene. This was done in order to keep the emission of benzene at a constant rate and therefore more accurately reflect the characteristics of the sources to be sampled in the field. On days when the wind speed exceeded 15 to 20 mph a more steady emission of benzene was achieved by using a heated bubbler. The bubbler system consisted of a 500 cc impinger of the Greenburg-Smith design wrapped with a heat tape. The impinger was kept at a constant temperature below the boiling point of benzene. Flow was regulated with a rotameter.

This series of experiments produced results accurate to within 10 percent of the theoretical mass to mass ratios when pure benzene was evaporated. These experiments were performed on days when the wind speed was light (5 to 10 mph) and the wind direction was steady.

Additional experiments were performed to test the variations which might be introduced when the wind speed was 20 to 25 mph and the direction was 180° variable due to a changing weather system. The rate of evaporation of the benzene was noticeably affected by the conditions as were the dispersion patterns of the emissions. Erratic results were produced by the meteorological stress of key experimental variables. Calculated mass to mass ratios differed from the theoretical value from 15 percent to as much as 56 percent, demonstrating the effect of high and variable winds on the technique. Because of the adverse effect of high gusty winds, the field measurements were performed on days when winds were light and steady.

Emission Measurement Results

As a result of the sampling program more than a dozen major sources of benzene emissions were identified. These sources are generally located in, or related to, the following processes: (1) tar separation and processing, (2) naphthalene separation and processing, (3) light-oil recovery, and (4) leaks from pumps, valves, exhausters, and other equipment components.

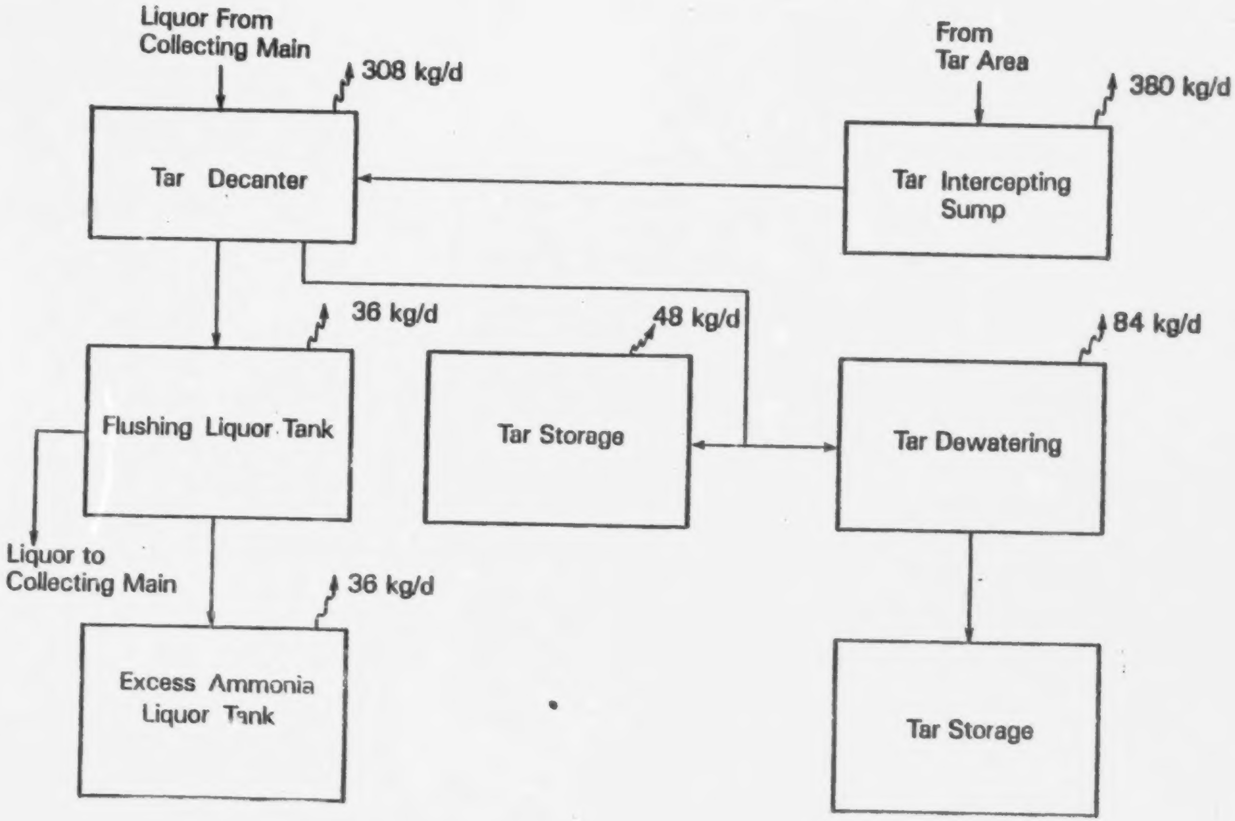
In the tar separation and processing operation (Figure 2) the heavy tar contained in the coke oven gases undergoes initial condensation when contacted with flushing liquor in the collecting main. The tar is generally removed from the process by tar decanters, the water content may be reduced in a tar dewatering vessel, and the tar is held in storage tanks pending use or sale.

The estimated emission factor for each source at a typical plant of 4,000 mg/day coke production is indicated on this slide. The two largest emission sources are the tar decanter and the tar intercepting sump.

Naphthalene is removed from the coke gas stream in the final cooler where water and naphthalene are condensed. Three types of final coolers, incorporating three methods for naphthalene separation, are currently used by the industry. These are: (1) direct-water final coolers, (2) a modification of direct-water final coolers called tar-bottom final coolers, and (3) wash-oil final coolers.

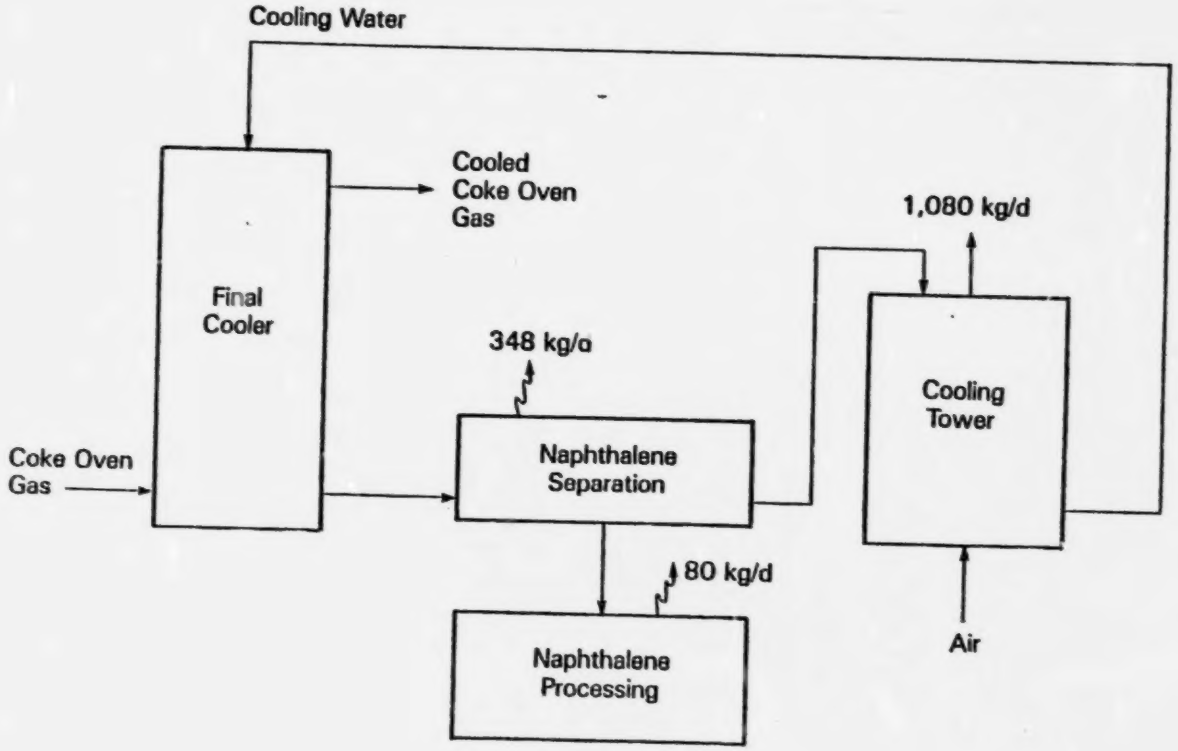
(Figure 3) When a direct-water cooler is used, the cooling mechanism is direct contact with cooled water. The condensed naphthalene must be removed from the water, and benzene emissions result when the crude naphthalene is processed. After the naphthalene is removed, the final cooler water is cooled by an induced-draft cooling tower. This water also contains benzene, which is released to the atmosphere when the water is cooled against air. At plants using direct-water final coolers, the cooling tower is usually the largest source of benzene emissions. This process is used by approximately 23 of 55 plants surveyed.

About 18 plants use tar-bottom final coolers. This system is similar to direct-water final coolers in that direct contact water is the cooling medium. It differs from direct-water final coolers in that the water is passed through a pool of tar in the bottom of a final cooler, where naph-


Liquor From
Collecting Main
308 kg/d
Tar Decanter
From
Tar Area
380 kg/d
Tar Intercepting Sump
36 kg/d
Flushing Liquor Tank
48 kg/d
Tar Storage
84 kg/d
Tar Dewatering
Liquor to
Collecting Main
36 kg/d
Excess Ammonia Liquor Tank
Tar Storage

EMISSION FACTORS ARE BASED ON AVERAGE TEST RESULTS

Figure 2. TAR SEPARATION AND PROCESSING (4,000 Mg/day coke production)


Cooling Water
Cooled
Coke Oven
Gas
1,080 kg/d
Final
Cooler
348 kg/d
Cooling
Tower
Coke Oven
Gas
Naphthalene
Separation
80 kg/d
Naphthalene
Processing
Air

EMISSION FACTORS ARE BASED ON AVERAGE TEST RESULTS

Figure 3. DIRECT WATER FINAL COOLER
(4,000 Mg/day coke production)

thalene collects in the tar. The tar is then transferred to the tar processing area previously discussed. All emissions from naphthalene processing are eliminated with this system. However, some benzene emissions still occur when the water is cooled against air in the final cooler cooling tower.

The third type of final cooler is infrequently used. Petroleum wash-oil serves as the cooling medium rather than water. Naphthalene dissolves in the wash oil, which is indirectly cooled by heat exchangers and recirculated to the final cooler. Benzene emissions resulting from naphthalene processing and from the cooling tower are virtually eliminated by this process.

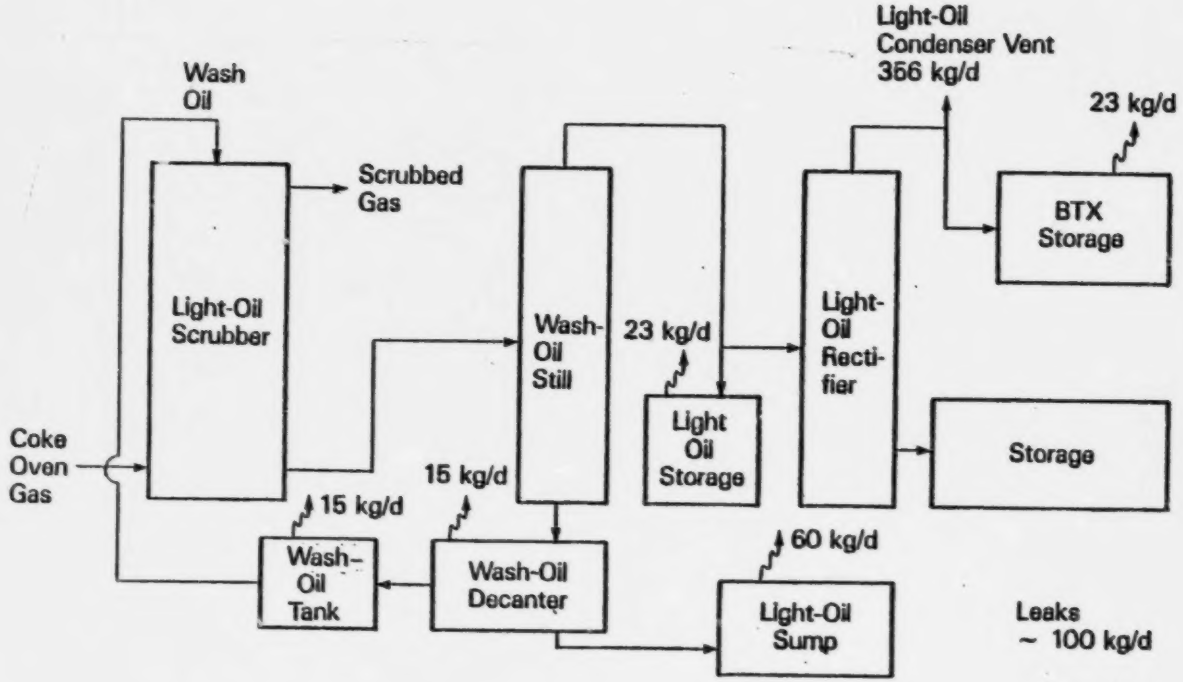
Light oil (Figure 4) is a clear, yellow-brown oil composed primarily of benzene. Light oil is recovered from the coke oven gas in a light-oil scrubber by using an organic scrubbing liquor called wash oil as the collecting medium. The wash-oil and light-oil mixture is separated by steam stripping and the wash oil is recycled to the scrubber. The greatest source of emissions in this area is the light-oil condenser vent.

Other sources of benzene fugitive emissions are leaks from process equipment such as pumps, exhausters and pipeline valves, and other equipment components in benzene service. Although total emissions from these sources depend on the number of sources at the plant, benzene emissions from these potentially leaking sources at a typical plant are estimated at approximately 100 kg/day.

Emission Control Techniques

During our evaluation of emission control techniques appropriate for by-product benzene sources, we found that a number of methods could be applied, including incineration, scrubbing with an organic solvent, carbon adsorption, condensation, source enclosure, leak detection and repair programs, process modification, and closed vent systems. Our study centered on the use of closed vent systems, source enclosures, process modification, and leak inspection and maintenance programs (Table 1).

The closed vent system (also referred to as coke oven gas blanketing) (Table 2) can eliminate emissions from most of the processes and is available to all plants because of the presence of the coke oven gas main and gas distribution system. The coke oven gas main transports gas from the coke ovens, through the by-product plant, and back to the ovens. The closed vent system is generally composed of piping, connections and valves which transport emissions from an enclosed source to the collection main, gas distribution system, or other enclosed point in the by-product recovery system. At a typical by-product plant, an estimated benzene process loss of about 4 percent results from losses from process vessels and product storage tanks. Depending on the design of a closed vent system, much of this estimated process loss can be prevented by recycling emissions to the gas main upstream of the benzene recovery operations. As an alternative, the closed vent system can transport vapor emissions to the clean coke oven


Wash Oil
Light-Oil Scrubber
Scrubbed Gas
Coke Oven Gas
Wash-Oil Still
23 kg/d
Light Oil Storage
Light-Oil Rectifier
Light-Oil Condenser Vent 356 kg/d
23 kg/d
BTX Storage
Storage
15 kg/d
Wash-Oil Tank
15 kg/d
Wash-Oil Decanter
60 kg/d
Light-Oil Sump
Leaks ~ 100 kg/d

EMISSION FACTORS ARE BASED ON AVERAGE TEST RESULTS

Figure 4. LIGHT-OIL RECOVERY
(4,000 Mg/day coke production)

Technique	Efficiency, %
Closed vent system	95-100
• Vent to battery collection main	
• Vent to fuel gas system	
• Vent to enclosed process	
Wash-oil scrubber	90
Vapor condensation for tar dewatering	95
Source enclosure for light-oil sump	98-100
Process modification	100
Leak detection and repair program	80-95

TABLE 1. EMISSION CONTROL TECHNIQUES

- Vent to gas distribution system
- Vent to enclosed process
- Benzene can be recovered
- Demonstrated at 7 plants
- 98 to 100 percent control

TABLE 2. CLOSED VENT SYSTEM

gas supply used to underfire the coke ovens, where the emissions can be incinerated and their fuel value recovered. Various adaptations of closed vent systems have been demonstrated at at least seven coke by-product plants. The control efficiency of the closed vent system is essentially 100 percent. Although this control technique has not been specifically demonstrated for some sources, this technique appears to be applicable to all sources except light-oil sumps, naphthalene processing operations, and most types of pumps, valves, and exhausters.

Although a closed vent system can be used to reduce benzene emissions from tar dewatering operations, the emissions can also be controlled at somewhat reduced efficiency by condensing the vapors in a heat exchanger and collecting the condensate. This control technique can be applied to tar-dewatering tanks because the emissions are often at elevated temperatures. The condensed water can be transferred to a flushing-liquor storage tank and the hydrocarbon layer can be returned to the tar. Engineering evaluations indicate that a properly operated and maintained condenser with an exhaust gas temperature of 45° C can provide a benzene emission control efficiency of about 95 percent. A wash-oil scrubber could also be used to remove benzene from the exhaust gas of tar dewatering. A spray tower could be used to prevent potential fouling by tar components. Depending on design factors wash-oil scrubbers can achieve efficiencies of 90 percent or higher.

For sources that do not have working losses such as the light-oil sump, a tightly fitting cover can be used to prevent wind from blowing across the surface and mixing with benzene or other hydrocarbon vapors. (Table 3) A closed system could be created by the installation of sealing mechanisms such as water seals or flexible seals. These seals would not generally need replacement if the sump cover is removed to permit access for sludge removal. A sealed sump cover enclosing the entire liquid surface area could achieve nearly 100 percent control efficiency.

A process modification can be applied to control benzene emissions from the naphthalene processing operations that are performed when a direct-water final cooler is used. (Table 4) This process modification would entail the absorption of the naphthalene in a medium such as tar or a petroleum wash oil. This would eliminate benzene emissions that are generated from the naphthalene processing operation when the naphthalene is separated from water. Though conceptual in nature and not currently used by the industry, the process modification is not extensive and is essentially the same principal used at plants having a tar-bottom final cooler. It would be needed only for the 23 plants that now use direct-water final coolers. (Figure 5) The modification involves passing the water from a direct-water final cooler through tar contained in a separate vessel called a mixer-settler before sending the water to the cooling tower. This control technique could also significantly reduce benzene emissions from the cooling tower, as compared with only a direct-water system.

Benzene fugitive emissions from leaking pumps, valves, exhausters, and other equipment components in benzene service can be reduced by leak detection and repair programs and by equipment, design, and operational require-

- Sump has no working loss
- Cover prevents evaporative loss
- Cover must be removable
- 98 to 100 percent control

TABLE 3 . COVER FOR LIGHT-OIL SUMP

- Eliminates naphthalene processing
- Not currently used
- Similar to tar-bottom final cooler

TABLE 4 . MIXER-SETTLER FOR DIRECT WATER FINAL COOLER

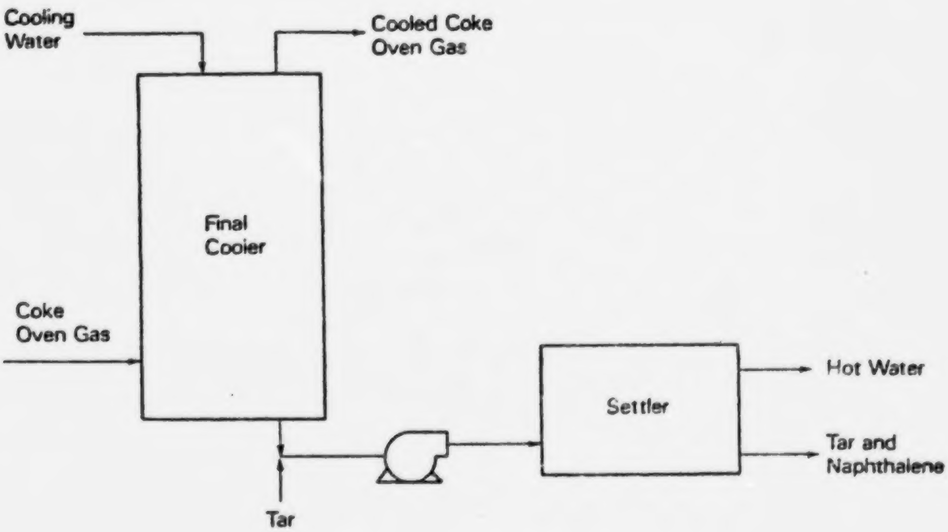

Cooling Water
Cooled Coke Oven Gas
Final Cooler
Coke Oven Gas
Settler
Hot Water
Tar and Naphthalene
Tar

Figure 5. TAR MIXER-SETTLER

ments. The leak detection and repair programs involve monitoring potential fugitive emission sources to detect fugitive emissions. After detection of a leak, the fugitive emission source would be repaired or replaced. These repair and replacement procedures would vary for each fugitive emission source. The effectiveness of the control technique depends on the frequency of the leak monitoring and repair.

A summary of industry-wide emissions for the sources identified is presented in the next slide (Table 5). This slide also shows what industry-wide benzene emissions would be if controlled using the technology presented in this paper. As you can see, benzene emissions from the sources identified can be reduced by about 90 percent.

Source	Industry emissions (Mg/yr)	Controlled industry emissions (Mg/yr)
Cooling tower (direct-water final cooler)	6,320	1,640
Tar-intercepting sump	5,450	0
Light-oil condenser vent	4,760	0
Tar decanter	4,420	221
Naphthalene processing	2,500	0
Cooling tower (tar-bottom final cooler)	1,210	1,210
Tar dewatering	1,110	55
Light-oil sump	800	16
Leaks	750	150
Tar storage	690	0
Light-oil, BTX and benzene storage	570	0
Flushing-liquor circulation tank	520	0
Excess-ammonia liquor tank	520	0
Wash-oil decanter	200	0
Wash-oil circulation tank	200	0
Total (rounded)	30,000	3,300

TABLE 5 . BENZENE EMISSIONS FROM COKE BY-PRODUCT RECOVERY PLANTS

The work described in this paper was not funded by the U.S. Environmental Protection Agency. The contents do not necessarily reflect the views of the Agency and no official endorsement should be inferred.

BLAST FURNACE CASTHOUSE EMISSION CONTROL WITHOUT EVACUATION

by: S. Vajda
Jones & Laughlin Steel Corporation
900 Agnew Road
Pittsburgh, Pennsylvania, 15227

ABSTRACT

During the past three years, J&L has developed an innovative proprietary technique for the control of blast furnace casthouse emissions. The technology, known as the Passive Emission Control (PEC) system, has been tested on three different J&L blast furnaces and was succsssful in complying with the opacity requirements of three states. Compliance was achieved without the use of fans and air cleaners. For the typical American furnace, certain additional benefits are available: (1) lower capital cost for installation, (2) the casthouse working conditions are better than those obtained with canopy-hood or total evacuation, (3) increased iron yield, (4) increased iron temperature. The system has been accepted by the U.S. EPA and at least five states.

INTRODUCTION

In the latter half of the seventies, most of the industrial point sources of air pollution were under control. As a result, EPA turned its attention to the control of fugitive emissions from blast furnace casthouse roof monitors. As part of their consent decree negotiations, J&L agreed to install blast furnace casthouse emission controls on its eight operating blast furnaces ranging in capacity from 2,400 to 4,500 tons of iron per day.

A review of the state-of-the-art disclosed a discouraging picture. On the North American continent, only two companies had control systems installed on four furnaces. These furnaces were smaller with a capacity of about 2,000 tons of iron per day. They were equipped with total evacuation systems rated at 400,000 ACFM. Thus, most companies in their preliminary planning were thinking total evacuation. However, for large furnaces, this technique required upwards of 600,000 ACFM. The estimated capital costs of $5 to 7 million per furnace were becoming prohibitive as were the fan operating costs.

For the two most modern furnaces to be built in the United States, plans were drawn for localized, closed-hood systems using 300,000 ACFM. For small furnaces, localized, closed-hoods over the iron trough using approximately 130,000 to 200,000 ACFM became relatively attractive options. To eliminate congestion on the casthouse floor, others planned localized, canopy-hoods in the roof trusses with air flows of approximately 330,000 ACFM. Where possible, to further reduce costs, common baghouses were being considered to serve several furnaces.

To achieve compliance for its eight operating furnaces by the conventional methods described above, J&L estimated that it would cost $35 million in capital and $2 million per year for power to operate the fans. This did not include the cost of baghouse and fan maintenance and dust disposal. In the face of such high costs, it was easy for J&L to conclude that it would be more productive to suppress the formation of fumes rather than to collect and remove them from the air.

Other facts which reinforced this decision were:

1. There was no improvement in the working conditions on the casthouse floor with total evacuation or canopy-hood systems.

2. EPA data indicates that fume generation in the closed-hood evacuation system is actually double of that in the total evacuation system i.e. approximately 1.3 lb. per ton [1] vs. 0.65 lb. per ton of iron.[2]

PRELIMINARY TEST PROGRAM

In the fall of 1978 at the Off-the-Record Casthouse Emission Control meeting sponsored by the AISE Iron Producing Division, J&L suggested that in view of the escalating costs of the total evacuation systems, it might be better to attack the cause of the fume formation rather than treat the resultant fume. After a brief discussion, the matter was dropped.

Nonetheless, for the better part of a year, J&L's Corporate Environmental Department conducted various trials and tests to see if indeed there was some validity to the premise that the formation of fume could be suppressed; and, if it could be reduced, what techniques were necessary to achieve the suppression. Observations of casts indicated the areas of concern in order of decreasing fume contribution were the iron trough, the iron ladles, the slag pots, and the iron and slag runners.

In early 1979, J&L conceived the use of an inert gas blanket above the surface of the liquid iron and/or slag to prevent the contact of oxygen with the liquid, thus suppressing the formation of fumes.

Subsequently, sufficient evidence was collected to show that the emissions could be reduced. It then became desirable to quantify as to how much. A cooperative steel company had an existing experimental canopy-hood installation over an iron trough. The duct from the hood offered an opportunity to measure the dust loading captured by the hood. Arrangements were made for a cooperative effort to try various suppression techniques and then to measure the dust loading under controlled and uncontrolled conditions. These efforts were mainly centered around maintaining a floating cover of inert materials such as coke breeze, vermiculite, rice hulls, etc. on the surface of the molten iron and slag. The tests indicated a 40 to 50% reduction of fumes. These results were not good enough for the host company so the cooperative effort was terminated.

J&L continued its efforts in testing. Then it equipped a casthouse with the most successful components and made movies of controlled and uncontrolled casts. These were then shown to the EPA personnel in Washington. They were so impressed with the potential possibilities that they requested the opportunity to witness a demonstration at the plant. Again, the results were promising enough that EPA gave J&L one year in which to further develop their ideas and to equip a furnace at each of three plants for a compliance demonstration test of 50 casts each.

DEVELOPMENT PROGRAM

J&L created a task force consisting of an operator, an engineer, and an environmental control representative from each plant under the chairmanship of a corporate environmental control engineer. In addition, the corporate refractory engineer and a corporate development engineer were included. It was the job of the latter, to independently proceed with the design and installation within a year of a canopy-hood over the iron trough for one furnace, in the event that the suppression technique failed.

Each plant was given the objective of developing fume control in a major area:

Plant #1. the iron trough
Plant #2. the iron and slag ladles
Plant #3. the iron and slag runners

Meetings were held monthly to discuss the successes and failures, the problems in getting equipment ordered, fabricated, and installed. Ideas were exchanged and evaluated, and progress plans made for the next four weeks. All reasonable suggestions were given a fair trial under operating conditions.

The use of a floating cover in the iron trough was very effective until the slag started running and the iron pool became turbulent. As the turbulence increased, the effectiveness deteriorated to such a point that it was negligible. Therefore, all three plants concentrated on the use of natural gas flames for fume suppression inasmuch as this was simple to use and could be applied on flowing surfaces and hard to reach places. This technique was more effective than the floating cover, but had as its chief drawbacks energy cost and the release of additional heat. J&L then moved on to other techniques which proved more effective and cheaper, and above all, had benefits additional to fume suppression.

The experimental and development work was not limited to the problem of fume suppression. Certain casthouse refractories were found to increase the generation of fumes. New materials had to be found. These turned out to be very expensive. Therefore, new runner designs and new application techniques had to be developed to give extended runner life and to reduce installation costs so as to offset the higher refractory costs. This effort has caused a complete reevaluation of the refractory requirements for casthouses on the part of the suppliers.

Additional facilities and personnel were recruited as required. For instance, in the problem of variable fume emissions from iron ladles; it was desirable to know when the ladle was spotted, whether the emissions would be heavy and require treatment or light and require none. Observations were made of 154 ladles during 72 casts. Twenty parameters such as ladle lining color, iron analysis, ladle build-up, kish in the ladle, track time, etc. were tabulated. The data was analyzed in a computer, but no correlation could be shown that was strong enough to predict with confidence whether a ladle should be treated or not. However, each plant had its own characteristic ladle pattern which led to a different control technique for each plant.

Because of unforeseen delays and change of personnel, the plants did not arrive at the compliance demonstration test deadline with the same degree of implementation. The control equipment ranged from prototype to generation I and generation II. Operator preference on casthouse practices led to different choices of refractories. Physical differences in the blast furnaces and the casthouse layouts also caused deviations not only in technique, but also in equipment. For instance, two of the demonstration furnaces have two tapholes and discharge their slag into pits outside the casthouse. The other furnace has a single taphole and discharges its slag into 8 slag pots inside the casthouse.

COMPLIANCE DEMONSTRATION TESTS

According to the rules set down by EPA, each furnace would be observed for 50 casts and would have to be in compliance for 45 casts with the applicable state opacity regulations. An observer would be on the casthouse floor to record the sequence of the cast and other pertinent information, while observers outside the casthouse recorded opacity levels every 15 seconds.

The first plant scheduled for the demonstration test was the Indiana Harbor Works. EPA specified that no emissions in excess of 40% opacity were permitted. The furnace tested was H-4 which has two tapholes and produces 4,500 tons of iron per day and has air-cooling slag pits.

The second plant scheduled for testing was Cleveland Works. The applicable regulation specifies that no emission above 60% opacity is permitted, but 20 to 60% opacity is permitted for 3 minutes per hour. The furnace tested was C-3 which has two tapholes, air-cooling slag pits, and produces 3,300 ton of iron per day.

Aliquippa was the third plant to be tested. The Pennsylvania state regulation is similar to that of Ohio. A-4 was the single-taphole furnace tested. It produces 2.700 tons of iron per day, and has 8 slag pots spotted inside the casthouse.

TABLE 1. COMPLIANCE DEMONSTRATIONS OPACITY OBSERVATION SUMMARY

PLANTS	CASTS	NUMBER	OPACITY, %
INDIANA HARBOR	46	15,797	3.9
CLEVELAND	50	10,122	4.2
ALIQUIPPA	58	13,570	4.2
TOTAL	154	39,489	4.1

Table 1 shows a summary of the test data. 154 casts were observed on the three furnaces with a total of approximately 40,000 opacity readings. The average opacity for all readings was 4.1%. The actual furnace averages varied from 3.9 to 4.2%.

TABLE 2. COMPLIANCE DEMONSTRATIONS OPACITY OBSERVATION SUMMARY

PLANTS	CASTS	NUMBER	IN EXCESS OF STANDARDS, %
INDIANA HARBOR	46	15,797	1.03
CLEVELAND	50	10,122	1.14
ALIQUIPPA	58	13,570	1.26
TOTAL	154	39,489	1.14

Table 2 shows that only 1.14% of the opacity readings were in excess of the applicable standards. The actual furnace averages varied from 1.03 to 1.26%.

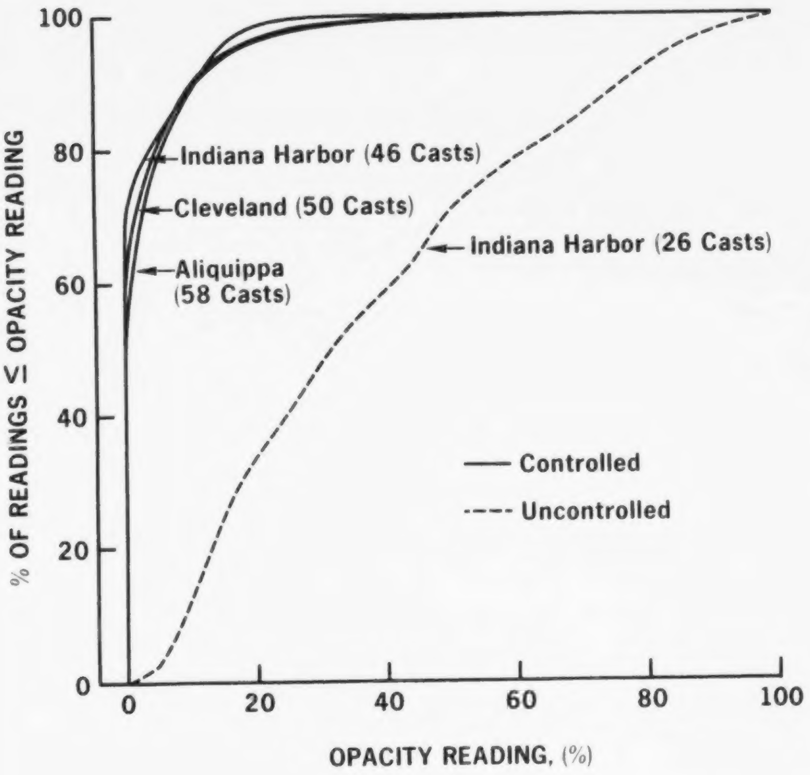


FIGURE 1. BLAST FURNACE COMPLIANCE DEMONSTRATIONS - CONTROLLED VS UNCONTROLLED CASTS

Figure 1 is a plot of the cumulative frequency of readings equal to or below a given opacity reading for the controlled casts of the three plants as compared to 26 uncontrolled casts taken at H-4 furnace at Indiana Harbor by the state of Indiana. The average opacity for the latter 4,423 observations was 39.9%. Tables I and II and Figure 1 emphasize the surprising uniformity of performance using the PEC system on three different sized furnaces, having different casthouse layouts, different operating personnel, and different observers.

Based on this data, EPA is recommending that reasonably available control technology (RACT) for blast furnace casthouses should limit emissions to 20% opacity based on a 6 minute moving average with no limit on the instantaneous peak opacity. The Passive Emission Control (PEC) system has been accepted by EPA Regions III and V and the three states in which the plants are located. Several other states have moved to modify their State Implementation Plans (SIPs) to accept the system as a viable alternate to evacuation systems.

BENEFITS OF THE PEC SYSTEM

As work progressed, it soon became evident that the original objective -- to bring the casthouse emissions under control -- was over-shadowed by other operating benefits. It seemed that everything that was done to suppress emissions improved both the furnace operation and the casthouse working conditions.

The following is a summary of the benefits of the PEC system:

1. Less capital cost. The J&L PEC system will cost $1 to 1.25 million per taphole to install as compared to $2.5 to 7 million for an evacuation type system requiring ducts, fans, and a baghouse.

2. Less installation time. Installation time is 4 to 6 months as compared to 15 to 18 months for evacuation systems.

3. Less operating costs. The J&L system does not require evacuation of air; therefore, the energy of 12,000 to 55,000 HP-hr per day per furnace is not required. Furthermore, the costs of fan and baghouse maintenance and dust disposal are eliminated.

4. Better casthouse working conditions. There is dramatically less heat and dirt on the casthouse floor as compared to total evacuation or canopy-hood systems.

5. Conservation of materials and energy. Since the PEC system does not require ducts, baghouses, and fans, it helps conserve the raw materials required to fabricate these facilities and the energy to manufacture them.

6. Less total pollution. The J&L system reduces the amount of fume generated. Furthermore, it eliminates the emissions made by the utility plant generating the power for the fans for the evacuation systems and for the manufacture of the evacuation equipment required. Finally, it eliminates collecting and handling the dust.

7. Less manpower on the casthouse floor. There is dramatically less work to prepare for the next cast. J&L has reduced the number of men working on the casthouse floor by two men per turn per taphole.

8. Increased iron yield. By eliminating the scrap and skulls in the iron runners, iron yield has been increased by 1%.

9. Increased iron temperature. An increase of 50 to 100°F in iron temperature permits a higher ratio of scrap to hot metal at the BOF resulting in increased steel production at plants with limited iron production. Alternatively, it can use the higher steel temperature for concast heats without a scrap usage penalty.

10. By using a new design for the iron trough, emissions are reduced, refractory costs are reduced, and the iron yield is increased 1% because

of better iron/slag separation.

11. For a typical 2,500 t/day furnace with slag pots, J&L estimates an annual savings of about $3 million for a capital investment of $1.5 million. This capital cost does not include the cost of materials expendable in less than 1 year. The increased refractory cost has been deducted from the annual savings shown.

J&L spent approximately $3 million on the development program. It did all of its own engineering with no outside guidance. New refractories and shapes had to be developed and tried on a trial and error basis. Operators had to use field expedients to try different ideas and concepts. All in all, it was a great team effort in previously untried areas. Because of the great expenditure of money and manpower, and because of the many benefits accruing from this technology, J&L can only offer its proprietary information under a secrecy and license option agreement. Therefore, it is with regret that more detailed information cannot be given in this paper. J&L has been granted patent protection for its process.

START-UP PROBLEMS

J&L has equipped three furnaces with the PEC system. However, because of business conditions only the C-3 furnace at Cleveland, which was blown in recently, has had the PEC system in intermittent operation for approximately one cycle. Because of furnace start-up problems, which had nothing to do with the emission control system, the integrated operation of the PEC system has been delayed. The life of the wear lining in the trough and runner systems has exceeded expectations. However, premature failure of the safety and insulating linings in the iron trough is the most recent cause of delay. Modifications are underway to correct these problems.

CONCLUSION

J&L has developed a cost-effective, new technique known as the PEC system for the control of blast furnace casthouse emissions. In its notice to announce final rule making on revisions to the Illinois SIP, EPA has said, "EPA has reason to change its view of what constitutes RACT for blast furnace casthouses due to a major technological innovation since the publication of the Notice of Proposed Rulemaking. EPA believes that the alternative hood-gas cleaner requirement imposed by the submitted rule is significantly more expensive and less emissions reductive for existing casthouses than is now achievable by the new non-capture operating and maintenance practices."[3] As noted previously, there are at least eight other major benefits using the PEC system.

J&L has equipped three furnaces with the new technology, two of which remain out of operation for business reasons. The C-3 furnace in Cleveland was recently put into operation and went through a series of start-up problems which have been resolved and the solutions are being implemented.

ACKNOWLEDGEMENT

I wish to express my appreciation and thanks to the many people who contributed their enthusiasm, ideas, and energy to make this project a success; especially to Mr. D.H. Miller, General Manager of Environmental Control, without whose faith and backing the project could have floundered.

REFERENCES

1. T.J. Maslany, P.D. Spawn, Blast Furnace Control Technology Update Fall 1981, EPA Iron & Steel Pollution Control Symposium, Chicago, IL, October, 1981.

2. P.D. Spawn, T.J. Maslany, and R. Craig, Status of Casthouse Control Technology in the United States, Canada, and West Germany in 1980, EPA Symposium on Iron & Steel Pollution Abatement, Philadelphia, PA, November, 1980.

3. Federal Register, Vol. 46, No. 171, September 3, 1981, page 44183.

This paper has completed the EPA peer review. However, it does not reflect the views of the Agency and official endorsement should not be inferred. The views presented are solely those of the author.

CRITICAL REVIEW OF ELECTRIC ARC FURNACE PARTICULATE EMISSIONS CONTROL TECHNOLOGY

by: Jaffer Mohiuddin
Pacific Environmental Services, Inc.
8230 Boone Boulevard, Suite 450
Vienna, Virginia 22180

ABSTRACT

There has been a tremendous growth in the use of electric arc furnaces (EAF) for the production of steel in the last two decades. In 1962, 9,013,000 tons of steel were produced using EAFs.* In 1980, this figure was 27,662,400 tons and in 1981,** EAFs accounted for 30,137,600 tons of steel.*** The increase in EAF steel by 1987 is expected to be about 5 million tons.**** In 1976, shipments of iron castings and steel castings totaled 15.3 million tons and 1.8 million tons, respectively. It is anticipated that these numbers will increase substantially in the near future.***** It appears that the contribution of EAF will continue to grow. This growth is due to the fact that EAFs offer certain advantages that are not offered by other types of furnaces. These include the ability to produce all known grades of steel, the ability to use scrap steel, and the flexibility of operation. They can be targeted to local markets and scrap supplies. Along with these advantages, EAFs are known to be significant producers of particulate matter emissions.

Currently, the systems that are used in controlling EAF particulate emissions include roof hoods, direct shell evacuation (DSE) systems, and side draft extraction systems for primary emissions. The secondary emissions are controlled by several techniques including canopy hoods and total building evacuation. In the recent past, several facilities have installed total furnace enclosure systems for the control of charging and tapping emissions.

---

* The Making, Shaping and Treating of Steel by United States Steel Corp., Ninth Ed., Herbick & Held, 1971.

** World Steel Statistics, Iron and Steel Engineer, August 1981.

*** World Steel Statistics, Iron and Steel Engineer, September 1982.

**** EPA Report 450/3-82-020a, "Electric Arc Furnaces & Argon-Oxygen Decarburization Vessels in Steel Industry - Background Information for Proposed Revisions to Standards (Preliminary Draft)," Sept. 1982.

***** EPA Report 450/2-78-024, Air Pollutant Control Techniques for Electric Arc Furnaces in the Iron and Steel Foundry Industry, 1978.

For the newer furnaces, there is a discernible trend towards employing total furnace enclosures due to several advantages. Furnace enclosures require air volumes from 30 to 40% of that required by an efficient canopy hood, considerably reducing both capital and operating costs for duct work, fans, and gas cleaning systems.

Several specially designed "close capture" systems are also in use in both fourndry and steel-making operations. These include the Hawley close capture hood, Brusa closed charging system, Armco tapping pit system, and steam emission suppression systems. In addition, there are other designs being tested, including the Marchand design.

This paper will review publicly available data on the existing, as well as emerging control technologies applicable to EAFs and their efficiency. A comparison of these control methodologies in terms of their capture efficiency and their relative cost-effectiveness will be made. Particular emphasis will be placed on identifying developing trends and their applicability to relative cost-effective EAF particulate emissions control.

PERFORMANCE OF EAF CONTROL TECHNOLOGIES

EMISSIONS AND REGULATORY REQUIREMENTS

From the environmental point of view, EAFs are a significant source of particulate emissions. The emissions from EAFs range from 15 to 40 pounds per ton for melting and refining and 1.5 to 2.0 pounds per ton for charging and melting*,** depending on the particular type and grade of charge. The regulatory requirements for the control of these emissions demand effective capture and collection of the particulates during all phases of EAF operations including charging, tapping, melting and refining, and all other related activities such as slagging and alloy addition. Some of the Federal and State requirements and standards are presented in Table 1.

For most of the existing regulatory requirements, the application of such primary control techniques as fourth hole extraction, lateral hood, and side draft extraction is not sufficient. A majority of the steel plants have found it necessary to install additional control systems for secondary emissions.

---

* EPA Report 450/3-82-020a, "Electric Arc Furnaces & Argon-Oxygen Decarburization Vessels in Steel Industry - Background Information for Proposed Revisions to Standards (Preliminary Draft)," Sept. 1982.

** EPA Report 450/2-78-024, Air Pollutant Control Techniques for Electric Arc Furnaces in the Iron and Steel Foundry Industry.

TABLE 1. EXAMPLES OF REGULATORY REQUIREMENTS AND STANDARDS

Standards/Requirements	Allowable Emissions
NSPS*	0.0052 gr/DSCFM Opacity from control device not to exceed 3%. Shop opacity due solely to EAF operations not to exceed 0%. Shop opacity greater than 0% but less than 20% during charging.** Shop opacity greater than 0% but less than 40% during tapping.**
Pennsylvania***	Allowable emissions $A = 0.76\ (40\ W)^{0.42}$ lb/hr where: W = Steel Produced, ton/hr Opacity not to exceed 20%, except for a period or periods aggregating no more than 3 minutes in any one hour or opacity not to exceed 60% at any time.

* *Federal Register*, 42FR 37936, July 25, 1977.

** Applied selectively.

*** Pennsylvania Air Pollution Regulations 123.13 and 123.41.

For the purpose of this paper, primary emissions are broadly defined as those emissions that result from EAF operations such as melting and refining, slagging, and alloy addition. The secondary emissions are defined essentially as those resulting from charging and tapping operations.

The control systems are primarily comprised of two components: the collection systems and the cleaning systems. A vast majority of cleaning systems employed are fabric filters -- although a few electrostatic precipitators (ESP) and wet scrubbers are also used. However, the collection systems vary significantly in terms of size, configuration, and other design parameters. The operation and performance of the cleaning systems have been studied in great detail. These studies indicate that the performance efficiencies of over 99 percent can be achieved.*

---

* EPA Report 450/3-82-020a, Electric Arc Furnaces and Argon-Oxygen Decarburization Vessels in Steel Industry - Background Information for Proposed Revisions to Standards (Preliminary Draft)," September 1982.

The collection systems, although based on general principles of air movement, are unique to a facility, dependent on factors such as structural and geometric considerations, shop secondary operations such as crane and forklift movements, material of construction, composition of emissions.

The collection systems generally used for capture of primary emissions include roof hoods, side draft hoods, and direct shell evacuation (fourth hole evacuation or DSE) and are presented in Figures 1, 2, and 3, respectively. These systems generally have very high particulate collection efficiencies, typically over 95 percent.* The systems used for collection of secondary (charging and tapping) emissions include canopy hoods, total building evacuation, total furnace enclosures, and specially designed "close capture" hoods. Canopy hoods are the most widely used secondary emission capture systems. The capture efficiency for canopy hoods is typically between 75 to 85 percent. The capture efficiency for sectional canopy hoods rises to 85 to 95 percent.* In the recent past, several facilities have installed furnace enclosures (doghouses, snuffboxes). Figures 4 and 5 present the schematics of canopy hood and furnace enclosures, respectively.

Of the systems used for primary particulate emissions control, DSE is the most effective. Since the collection is done through the roof of the furnace, low gas volumes are required; however, it has a few drawbacks. Certain alloys/metals require certain environments in the furnace to properly control and maintain the chemistry, in order to obtain the desired specifications of the product. This sometimes precludes the use of DSE. Also, the DSE system must be constructed of materials that can withstand the high temperatures of the exiting gas. Often times, gas cooling is required.

Other systems such as roof hoods and side draft hoods capture the emissions after exiting from the furnace. For this reason, their capture efficiency is not as high as DSE. But their advantages include use of material of construction which is less heat resistant, and often times do not require gas cooling.

The most common secondary emissions control is the canopy hood. Many facilities across the United States employ this type of collection device. In this system, emissions are captured by a canopy which envelopes the space above the furnace. The design and construction of canopy hoods is primarily dependent on the structural and geometric considerations within the melt shop. Canopy hoods are normally 20 to 50 feet above the furnace. Because of this distance from the source, exhaust flows must be high for effective capture of the emissions. Although thermal currents facilitate the upward movement of the fumes, the flow rates required are much higher than for primary emissions capture. In turn, this higher flow rate effects the size and therefore, the cost of the gas cleaning system.

At some plants, the canopy hoods are divided into two or three sections. In the two-sectioned hood, one section is used for the capture of charging

---

* EPA Report 450/3-82-020a, Electric Arc Furnaces and Argon-Oxygen Decarburization Vessels in Steel Industry - Background Information for Proposed Revisions to Standards (Preliminary Draft)," September 1982.

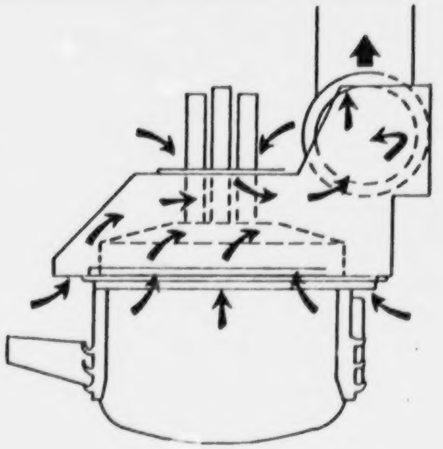


Figure 1. Roof Hood

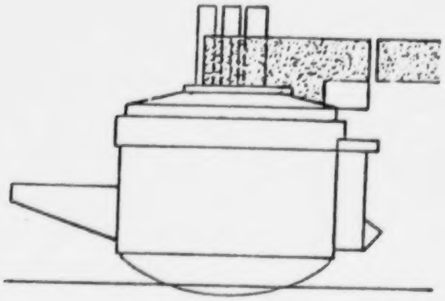


Figure 2. Side Draft Hood

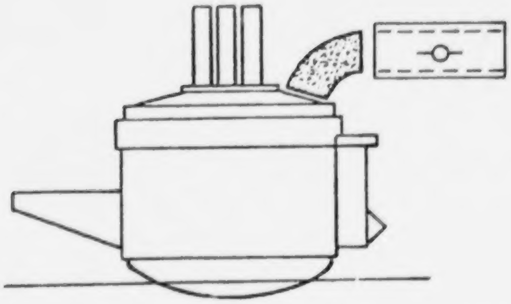


Figure 3. Direct Shell Evacuation

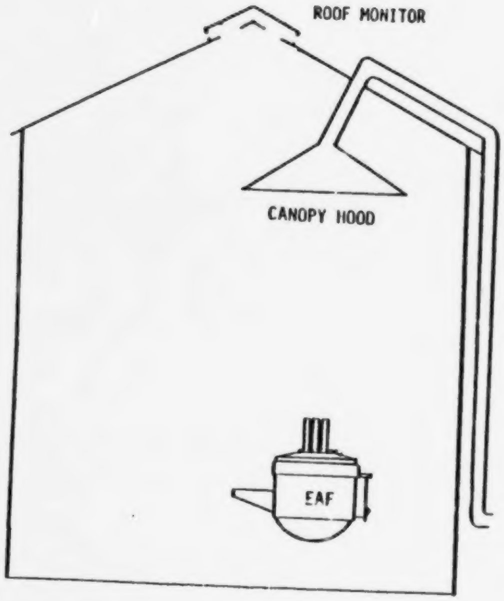

ROOF MONITOR
CANOPY HOOD
EAF

Figure 4. Canopy Hood

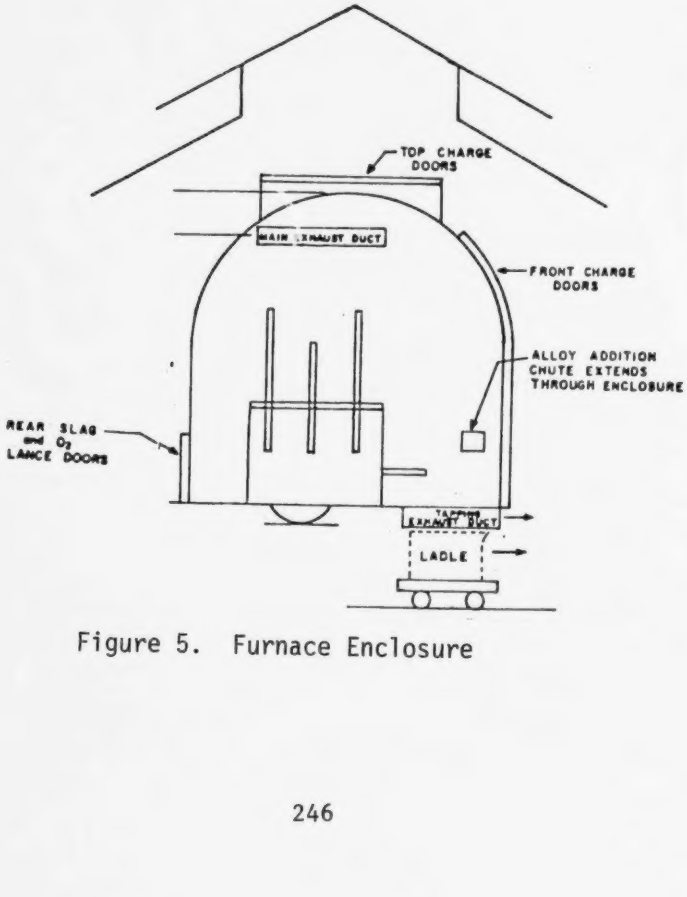

TOP CHARGE DOORS
MAIN EXHAUST DUCT
FRONT CHARGE DOORS
ALLOY ADDITION CHUTE EXTENDS THROUGH ENCLOSURE
REAR SLAG and O_2 LANCE DOORS
TAPPING EXHAUST DUCT
LADLE

Figure 5. Furnace Enclosure

emissions and the other for tapping emissions by the appropriate use of dampers. Some plants have divided the hood into three sections. The three sections are arranged to capture slagging, charging and melting, and tapping emissions.

A scavenger duct system helps improve the capture efficiencies of the canopy hood. It essentially consists of small auxiliary ducts located above the canopy hood near the roof. A small flow rate (about 10% of the total flow rate) is maintained through these ducts to capture particulate emissions that are not captured by the canopy hood systems.

The factors that effect proper capture of fumes include diversion from the canopy due to impingement or obstructions such as overhead cranes and structures, secondary operations such as movement of forklifts, and the cross drafts inside the building.

Some plants use partitions coming down from the canopy hoods to reduce the effect of cross drafts and to increase the retention time. Other forms representing this technique, such as partial furnace enclosures are also used. The partial furnace enclosures are comprised of walls on three sides of the furnace. These walls direct the secondary emissions to the canopy hoods and reduce the effect of cross drafts. They also contribute to the reduction of noise and radiant heat.

Tapping hoods are being increasingly used in newer emission capture designs. They have several different designs, usually involving a movable or stationary hood that is located above the tapping ladle when tapping is carried out. At other times, the tapping hood is moved away.

Furnace enclosure is a technique used for the capture of primary and secondary EAF emissions. Furnace enclosure essentially consists of a metal shell which completely encloses the furnace and tapping area. A hood or a large exhaust duct near the top of the enclosure removes charging and melting fumes. Tapping emissions are generally collected by a local hood for the ladle. Sliding doors permit the entry of the charging bucket.

In the recent past, several companies have installed furnace enclosures to control EAF emissions. Although the experience of operating these systems is limited compared to canopy hoods or other established systems, certain conclusions can be drawn. Furnace enclosures in conjunction with properly designed gas cleaning meet most of the current Federal, State, and local regulations. One company* rates the furnace enclosures as excellent and a practical solution to noise control. Operator fatigue is reduced since the personnel are not exposed to high levels of sound as well as radiant heat. The furnace is not crowded with primary control systems, thus simplifying repairs and maintenance. Furnace enclosures eliminate cross drafts, thus reducing fumes in the work area and improving working conditions. Lower gas volumes are required.

---

* Dust Collection of Electric Arc Furnace at Maynard Steel Co. by Doghouse Evacuation, T. Pankratz, AFS Transactions 82-11.

There are also some problems associated with the operation of a furnace enclosure. Charging and tapping is problematic due to the inability of the craneman to see what is being done. He has to rely on the ground man's directions. This is not an insurmountable problem but needs to be addressed. Because of a lack of air movement across the roof, the roof runs hotter. This effects the roof refractory life. Also, cooling the roof takes longer which adds problems to repair and maintenance scheduling. Electrodes need to be monitored very closely, in order to prevent interference with the structures when tilting if they are too long or to avoid an addition while on a hot roof, if the electrodes are too small.

AIR VOLUMES

Since the emissions have a linear relationship with steel produced, they are linearly proportional to the furnace capacity or the heat size. Consequently, the extraction air volumes required are dependent on the furnace capacity. The air volumes required for primary emissions extraction can best be described by the relationship:

$$(\mathrm{SCFM}) = C \times HC \qquad (1)$$

where: C = Capacity factor, SCFM/ton
HC = Heat capacity, ton

For the secondary control systems, using a canopy hood for the emissions capture, the air volumes entering the canopy can be best described by:

$$Q = 34.24\,(D_S)^{2/3}\,(Y + D_S)^{1.67} + 24.55\,(Y + D_S)^{1.67} \qquad (2)$$

where: D_S = Diameter of the EAF
Y = Height of canopy hood over the furnace
Q = Air volume going into the canopy, ACFM

This equation is based on the Hemeon analysis,** and the main assumption for the derivation of these constants is the temperature difference between the open furnace mouth and the hood face which is 3000°F.

The extraction air volumes for secondary emissions for a total furnace enclosure system depend to a large extent, on the enclosure volume and the characteristics of the gas cleaning systems. They are found to be on the order of 100,000 to 150,000 acfm.***,**** (A large 22-foot diameter UHP furnace with a capacity of 170 tons per heat for furnaces of up to 60 tons per heat) employs a furnace enclosure with an extraction volume of 471,000 ACFM.

---

* Environmental Policy for the 1980's: Impact on the American Iron and Steel Industry, Report to the American Iron and Steel Institute, Arthur D. Little, Inc., 1981.

** Hemeon, W.C.L., "Plant and Process Ventilation," Second Edition, The Industrial Press, New York, New York.

*** PEDCo Environmental Report, ESED No. 79/9, "Visible Emission Survey Report, Hoeganaes Corporation, Gallatin, Tennessee," November 1980.

**** Brand, P.G.A., "Current Trends in Electric Arc Furance Emission Control," Iron and Steel Engineer, February 1981.

SYSTEM PERFORMANCE

The purpose of the regulatory requirements is to mitigate the introduction of the particulate pollutants into the atmosphere. Therefore, the evaluation on the system performance entails a qualitative and quantitative estimate of the emissions that are exiting the melt shop, as well as the air cleaning systems. This is normally performed by standardized methods. In practice, this involves determining the mass emissions from the gas cleaning system and visible emissions from both the gas cleaning systems, as well as the melt shop building. The emissions that are not captured by the collection systems such as canopy hoods, exit through apertures such as roof monitors.

A comparison of performance in terms of mass and visible emissions of two facilities with similar furnaces but using different control systems will be enlightening. The melt shop at facility #1** has an EAF with a capacity of 50 tons per heat and a shell diameter of 16 feet. Emissions from the EAF are captured by an overhead canopy hood. The flow rate is approximately 190,000 ACFM and the gas cleaning device is a baghouse.

Facility #2* has an EAF with a capacity of 55 tons per heat and a shell diameter of 14 feet. The control system is essentially comprised of a furnace enclosure. There is, however, a canopy atop the enclosure to provide additional capture of any emissions that may have escaped the enclosure. The baghouse has a rated capacity of 150,000 acfm (150°F).

Both facilities are in compliance with the mass emission requirements of the new source performance standards (NSPS). An extensive visible emission evaluation indicated that both facilities are in compliance with the requirements. However, the air volumes required by the facility with total furnace enclosure is less by about 40,000 acfm. This air volume will have a significant effect on the operating costs.

CAPITAL AND ANNUALIZED COSTS

Table 2 presents the capital and annualized costs of control systems employed for the control of primary and secondary EAF emissions. The costs are limited to DSE-canopy hood systems. This is due to the fact that cost data for other types of systems is not generally available. However, the estimate for a turn-key furnace enclosure for a 20 ton per heat furnace was about $750,000 in 1978.** The capital costs for furnace enclosure, ducting, and auxiliary equipment excluding gas cleaning device at a facility with a 60-ton per heat furnace amounted to $900,000 (1976 dollars). The cleaning system, a specially designed steam scrubber, using exiting waste heat boiler and slurry treatment facilities, had capital costs of $200,000 (1976 dollars).* More recent estimates are not available.

---

* PEDCo Environmental Report, ESED No. 79/9, "Visible Emissions Survey Report, Eastern Stainless Steel Company, Baltimore, Maryland,"

** Dust Collection of Electric Arc Furnace at Maynard Steel Co. by Doghouse Evacuation, T. Pankratz, AFS Transaction 82-11.

TABLE 2. CAPITAL AND ANNUALIZED COSTS OF AIR POLLUTION CONTROL EQUIPMENT FOR EAF*,**

Furnace Capacity (tons/heat)	Annual Production (tons/year)	Flow Rates		Capital Costs*** $\$10^6$	% of Total Capital Costs****	Annualized Costs	
		DSE	Canopy Hood			$\$10^3$	$/ton*****
25	41,250	30,000	96,250	1.73	19.8	500.8	12.14
100	163,300	120,000	265,000	4.37	17.9	1411.7	8.64
300	596,000	360,000	395,000	4.87	16.0	2230.5	3.74
150(UHP)	434,800	192,000	378,000	6.29	16.0	2316.9	5.40

* EPA Report 450/3-82-020a, "Electric Arc Furnaces & Argon-Oxygen Decarburization Vessels in Steel Industry - Background Information for Proposed Revisions to Standards (Preliminary Draft)," Sept. 1982.

** Includes control device, capture devices, ductwork, and solid waste handling.

*** Includes direct and indirect capital costs.

**** Total plant investment includes costs of melt shop and pollution control equipment.

***** Costs per ton of steel produced.

The control system capital costs, prescribed in Table 2, include purchase of the baghouse and auxiliary equipment such as canopy hood, fans, ductwork, and solid waste handling systems, as well as direct and indirect installation costs. The direct installation costs include: cost of foundation and support, handling and erection, electrical wiring, piping, and painting. Indirect costs include: engineering and supervision, construction expenses, startup, performance tests, and contingencies. The annualized costs include direct operating costs such as utilities, labor, parts, and solid waste transfer. Indirect operating costs include plant overhead, capital charges, and capital recovery costs.

COMPARISON OF COST ESTIMATES

The annualized costs per unit of particulate emission reduction from EAF operations with a DSE-canopy system is presented in Table 3. A comparison of cost estimates of DSE-canopy systems with furnace enclosure systems at this point of time is not possible due to the very limited availability of data pertaining to furnace enclosures. The same is true for other proprietary systems. However, a comparison of available technical data indicates that furnace enclosures for a given size of furnace perform equally well, if not better than canopy hoods with much lower volumes of air, in addition to the several advantages mentioned previously.

---

* Air Pollutant Control Techniques for Electric Arc Furnaces in Iron and Steel Foundry Industry, EPA-450/2-78-024, June 1978.

TABLE 3. ANNUALIZED COSTS PER UNIT OF PARTICULATE EMISSION REDUCED

Furnace Capacity	Emission Reduction*(10^6 lb)	Annualized Costs $/lb ($/ton)
25	1.24**	0.41 (918)
100	4.92**	0.29 (650)
300	17.94**	0.12 (269)
150	17.22***	0.14 (314)

* Based on canopy hood efficiency of 80% and DSE efficiency of 95%.

** Based on emission factors of 30 lb per ton for melting and refining and 2.0 lb per ton for tapping and charging.

*** Based on emission factor of 40 lb per ton for melting and refining and 2.0 lb per ton for tapping and charging.

Using an equation of the type

$$CI = 179.8\ (SCFM)^{0.76} \cdot ENRR^{*} \qquad (3)$$

where: CI = Capital investment ($)
SCFM = Flow rates (scfm)
ENRR = Ratio of Engineering News Record indices

A comparison for the capital costs of a furnace enclosure system and a DSE-canopy system can be made. For example: the air volume flow rates for furnaces of 25-ton capacity for these two systems is 70,000 SCFM and 125,000 SCFM, respectively. Using this equation, the ratio of capital investment for the furnace enclosure to DSE-canopy system is 0.64. Current available data indicate a capital cost ratio of about 0.43. These two ratios seem compatible within a reasonable range.

SUMMARY

Given the fact that furnace enclosures are installed and operated on only a few small furnaces (20 to 60 tons per heat), the available operational and cost data are limited. However, the comparison of available operational data indicates that performance of furnace enclosures for similar sized furnaces vis-a-vis the collection of primary and secondary particulate emissions is superior to more commonly used systems such as the DSE-canopy hood. The air volumes required are also smaller. Air volume requirements impact the size of the cleaning system. For this reason, lower capital and operational costs are incurred.

---

* Environmental Policy for the 1980's: Impact on the American Steel Industry, Report to American Iron and Steel Institute, Arthur D. Little, Inc., 1981.

There are engineering and operational problems associated with furnace enclosures such as crane movement, effect on roof refractory life, and maintenance and repair problems. These problems may not be insurmountable if due consideration is given to the potential cost savings, both capital and operational, that can accrue from the furnace enclosure system.

SESSION 4: WATER POLLUTION ABATEMENT

Chairmen: John S. Ruppersberger
Industrial Environmental Research Laboratory
U.S. Environmental Protection Agency
Research Triangle Park, NC

S. Charles Caruso
AISI Environmental Resources Project
Mellon Institute
Pittsburgh, PA

The work described in this paper was not funded by the U. S. Environmental Protection Agency. The contents do not necessarily reflect the views of the Agency and no official endorsement should be inferred.

DEVELOPMENT OF A ROTATING-BIOLOGICAL-CONTACTOR FOR THE REMOVAL OF AMMONIA FROM BLAST-FURNACE RECYCLE-WATER BLOWDOWN

by: K. C. Krupinski and P. H. Damon
United States Steel Corporation
Research Laboratory
125 Jamison Lane
Monroeville, PA 15146

ABSTRACT

Proposed Federal regulations have established effluent contaminant limitations on discharges from blast-furnace gas-cleaning recycle-water systems. To meet the proposed limits for ammonia, the major contaminant, the blowdown from these systems may require treatment. As a part of the development of alternative processes for the discharge-water treatment, a supported-growth biological method for the oxidation of ammonia was investigated. An extensive program with a pilot rotating-biological contactor was conducted for about one year at the U. S. Steel Lorain-Cuyahoga Works in Lorain, Ohio. The pilot unit contained commercial-sized 12-foot-diameter disks and was operated over a wide range of influent water conditions, with ammonia-nitrogen concentrations averaging 329 milligrams per litre (mg/ℓ). Reductions in ammonia-nitrogen concentrations to 1 mg/ℓ were achieved with the process demonstrating excellent resistance to simulated failure conditions along with the potential for low maintenance and a low level of operator attention.

BACKGROUND AND INTRODUCTION

During the manufacture of iron in the blast furnace, large quantities of flammable gas are produced. The gas has a heating value of about 80 Btu per cubic foot and contains about 25 volume percent carbon monoxide, 3 percent hydrogen, 12 percent carbon dioxide, and 60 percent nitrogen.(1)* The gas also contains entrained dust that must be removed before the gas can be used as a fuel. The wet scrubbing used to clean the gas results in the introduction of various contaminants, such as ammonia, into the process water.

The Clean Water Act of 1972 mandated a two-phase reduction in the amount of contaminants discharged with the blast-furnace gas-cleaning process water. The iron and steel industry complied with the requirements of the first phase by recycling the blast-furnace gas-scrubber and cooling water, thereby substantially reducing the amount of water and contaminants discharged. The next phase in the contaminant-reduction program must be implemented by 1984 and will require treatment of the blowdown from the blast-furnace recycle-water systems. The gas-scrubbing and recycle-water system is illustrated in Figure 1.

---

* See References.

Currently the Environmental Protection Agency recommends the use of alkaline chlorination for the treatment of blast-furnace recycle-water blowdown. However, alkaline chlorination is a costly and complex process which has potential chlorine-handling problems. A much simpler and less expensive alternative treatment would be the biological oxidation of the contaminants, but the standard suspended growth process cannot be used because the ammonia-converting organisms are slow growing and would be lost from the treatment tank. In the present investigation this problem was solved with the rotating-biological contactor (RBC) unit which provides a support for the organisms.

An RBC consists of a series of closely spaced circular polyethylene disks (media) fixed to a horizontal shaft mounted across a tank with about 40 percent of each disk submerged in the wastewater. The shaft is continuously rotated at about 1.5 revolutions per minute and a biological slime (biomass) grows on the media by using the contaminants present in the wastewater as food. Aeration is provided by the rotating action, which repeatedly exposes the disks to the air after contacting them with the wastewater. Excess biomass is sheared off in the tank where the rotating action of the media maintains the solids in suspension so they can be transported from the RBC unit.

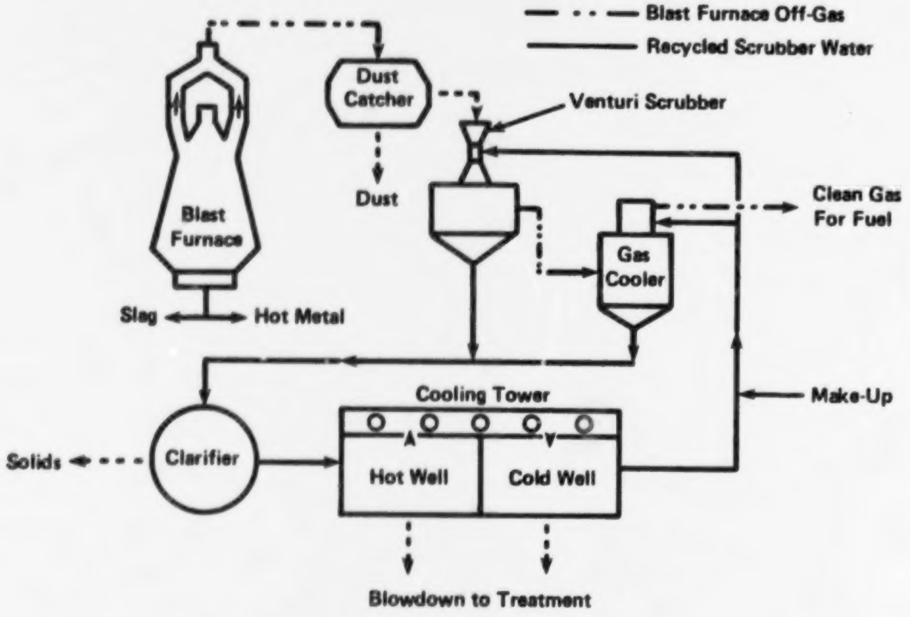
Although this process has been developed primarily for the oxidation of ammonia, the major contaminant in blast-furnace recycle water, other biologically oxidizable contaminants such as cyanate, cyanide, and phenol can also be removed by the RBC process. However, contaminants which are not biologically oxidizable, such as heavy metals, may require a separate chemical treatment.

The bacteria responsible for the oxidation of ammonia-nitrogen (NH_3-N) to nitrate-nitrogen (NO_3-N), collectively called nitrifiers, consist of the genera Nitrosomonas and Nitrobacter.2) The oxidation of ammonia to nitrate is a two-step sequential reaction as follows:

$$2NH_4^+ + 3O_2 \xrightarrow{\text{Nitrosomonas}} 2NO_2^- + 4H^+ + 2H_2O$$

$$2NO_2^- + O_2 \xrightarrow{\text{Nitrobacter}} 2NO_3^-$$

Nitrosomonas oxidizes ammonia to nitrite (NO_2^-) and Nitrobacter oxidizes NO_2^- to nitrate (NO_3^-). The overall oxidation reaction can be written



Blast Furnace Off-Gas
Recycled Scrubber Water
Dust Catcher
Venturi Scrubber
Dust
Blast Furnace
Clean Gas For Fuel
Gas Cooler
Slag
Hot Metal
Cooling Tower
Make-Up
Solids
Clarifier
Hot Well
Cold Well
Blowdown to Treatment

Figure 1 Blast-Furnace Gas Scrubber Recycle Water System

$$NH_4^+ + 2O_2 \longrightarrow NO_3^- + 2H^+ + H_2O$$

Assuming that the empirical formula for the bacterial cells is $C_5H_7NO_2$, the overall synthesis and oxidation reaction is[3)]

$$NH_4^+ + 1.83\ O_2 + 1.98\ HCO_3^- \longrightarrow 0.021\ C_5H_7NO_2 +$$

$$1.041\ H_2O + 0.98\ NO_3^- + 1.88\ H_2CO_3$$

From this equation it can be calculated that for each pound (lb) of NH_3-N oxidized the following are required:

1) 7.14 lb of alkalinity, as calcium carbonate ($CaCO_3$), to neutralize the acid produced.

2) 0.72 lb of alkalinity, as $CaCO_3$, to provide a carbon source for bacteria growth.

3) 4.18 lb of oxygen for the oxidation reaction (the oxygen is obtained from the air via the rotating disk).

To develop design data and evaluate the costs of the RBC system, U. S. Steel Research operated a pilot-scale RBC at the Lorain-Cuyahoga Works, Lorain, Ohio for about 1 year. The results of the study are presented in this paper.

MATERIALS AND EQUIPMENT

A single full-sized RBC unit, for which the specifications are summarized in Table 1, was used in the study. The pilot unit contains the same type of 12-foot-diameter polyethylene disks that are used in a full-scale RBC. The only major difference between the pilot- and full-scale units is the amount of surface area available for biomass growth.

The disk system used in the pilot unit is shown in Figure 2 before installation in the 2800-gallon tank, and the fully installed RBC is pictured in Figure 3 along with the RBC effluent clarifiers. The disks are shown uncovered in Figure 3 but during portions of the pilot study the disks were covered with polyethylene sheeting to prevent heat and water loss due to evaporation. The RBC tank is divided into four cells, each holding 700 gallons of water, which can be operated in a series of stages or in parallel depending on the position of the valves located on the feed-line manifold. The flow to the unit was controlled by metering pumps.

A typical flow pattern through the RBC is shown in Figure 4. The first three cells were usually operated in series and the fourth cell was

TABLE 1. PILOT RBC SPECIFICATIONS

Media (disks):	Diameter - 12 foot Material - Polyethylene with carbon black UV inhibitor
Cells:	4
Tank Volume:	2,800 gallons; 700 gallons/cell
Disk Rotation:	1.5 rpm

TABLE 2. RBC ANALYSES - FREQUENCY AND METHOD

Once a day

a. pH - Orion Model 701 Digital pH meter
b. Dissolved oxygen - Orion Model 97-08 Oxygen Electrode
c. Temperature - Tel-Tru Dial Thermometer, Range 0 to 180°F
d. Conductivity - Markson Model 10 Portable Conductivity Meter
e. Alkalinity - Titration with 0.03N HCl using brom cresol green - methyl red indicator
f. Free cyanide*
g. Ammonia-nitrogen**

Twice a week**

a. Nitrite - nitrogen
b. Nitrate - nitrogen
c. Phosphate
d. Thiocyanate
e. Chemical oxygen demand
f. Cyanate
g. Cyanide, total
h. Phenol
i. Total suspended solids
j. Volatile suspended solids

Once a week

a. Hardness - Titration with ethylenediaminetetraacetic acid

---

*American Iron and Steel Institute Method.

**Methods for Chemical Analysis of Water and Wastes, U. S. Environmental Protection Agency, EPA-6000/4-79-020, March 1979.

Figure 2. Disk Assembly Used
in Pilot Rotating-
Biological Contactor

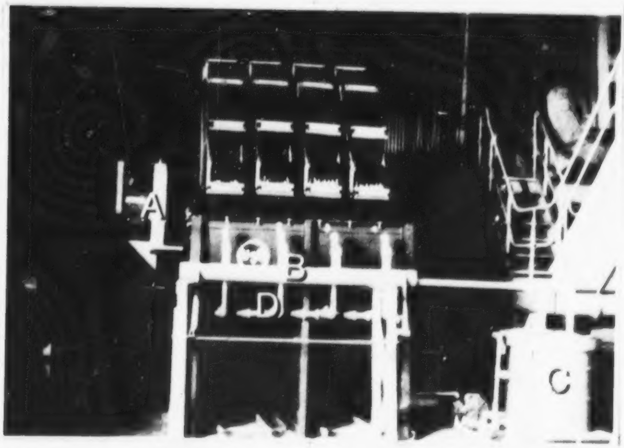


Figure 3. Pilot Rotating-Biological Contactor
A-Drive Motor
B-Effluent Trough (Treated Water)
C-Clarifiers
D-Manifold Flow-Control Piping

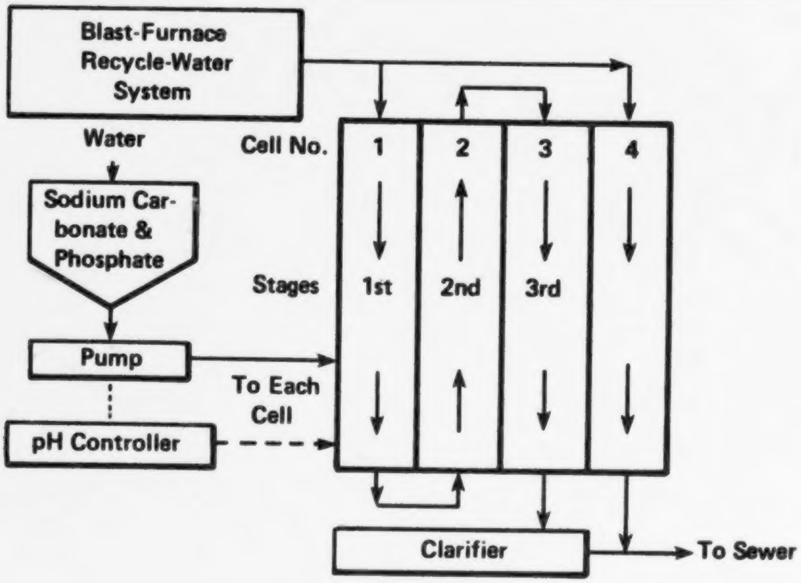

Blast-Furnace Recycle-Water System
Water
Sodium Carbonate & Phosphate
Pump
pH Controller
To Each Cell
Cell No.
1
2
3
4
Stages
1st
2nd
3rd
Clarifier
To Sewer

Figure 4 Schematic of RBC Flow Pattern

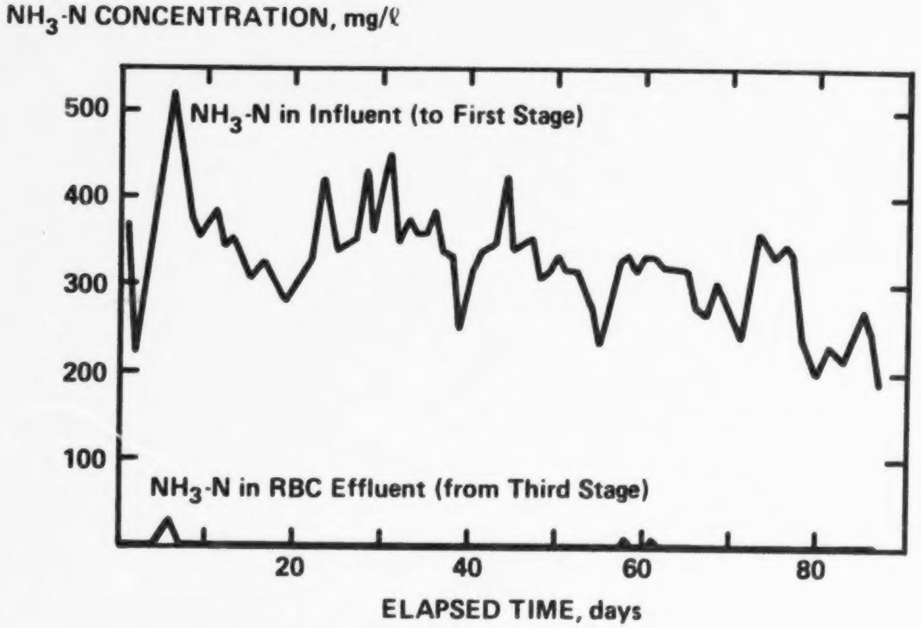


Figure 5 RBC Demonstration Test—NH_3-N Concentration in RBC Influent and Effluent (3-Stage Operation)

operated independently. The pH of each cell was independently controlled at 7.2 by means of a pH controller and a sodium carbonate solution pump. Phosphoric acid was added to the sodium carbonate solution to provide phosphorus, a required nutrient.

START-UP

To initiate the growth of the biomass, the RBC was seeded with sludge from a coke-plant biological-treatment facility. The unit was filled with plant-service water to which was added 10 milligrams per litre (mg/ℓ) of NH_3-N as ammonium hydroxide and 100 gallons of the biological sludge. A mixture of blast-furnace recycle-water blowdown and river water was then metered to the RBC. The initial concentration of blowdown in the service water was 10 percent, and as the biomass developed, the percentage of blowdown was gradually increased to 100 percent over a three-week period. During the first 15 days of start-up, a portion of the RBC effluent was recycled to return any nitrifiers lost in the effluent and to enhance the seeding process.

ANALYSES

Analyses of the RBC influent and effluents were performed on grab samples except for influent NH_3-N, which was determined on a 24-hour continuously composited sample. The only parameter continuously recorded was pH; all other analyses were performed once a day, twice a week, or once a week, as indicated in Table 2.

DEMONSTRATION TEST

An 87-day demonstration test was conducted during the pilot testing program. The purpose of the test was to duplicate, as closely as possible, the conditions that would be expected to exist in a full-scale RBC facility. The RBC influent was taken from the cooling-tower hot well; cells 1, 2, and 3 were operated in series; the disk assembly was covered and insulated; and the influent flow was maintained at a fairly constant rate. The NH_3-N concentrations in the influent to stage 1 cell and effluent from stage 3 cell are plotted in Figure 5, and the averaged test data are summarized in Table 3.

During the demonstration test the NH_3-N concentration in the RBC influent varied between 190 and 520 mg/ℓ and the average NH_3-N content of the RBC effluent was 1.1 mg/ℓ. No equalization of the RBC influent was provided during the pilot study, but a tank providing concentration equalization would be a requirement in a full-scale facility.

As shown in Table 3 the NH_3-N, thiocyanate, cyanate, and free cyanide were almost completely converted to nitrate. The alkalinity of the influent was consumed, and additional alkalinity as Na_2CO_3 was added during the demonstration test to neutralize the acid produced. The hardness did not decrease, indicating no scaling or calcium precipitation, and the dissolved solids increased because of the addition of Na_2CO_3. The

TABLE 3. RBC DEMONSTRATION-TEST-DATA SUMMARY* THREE-STAGE SERIES FLOW

	RBC** Influent	RBC Effluent
Water Temperature, °F	101.	82.
pH, SU	7.48	7.21
Alkalinity, mg/ℓ $CaCO_3$	554.	35.
Hardness, mg/ℓ $CaCO_3$	1250.	1270.
Conductivity, $\frac{\mu mhos}{cm}$	6320.	6840.
Dissolved Oxygen, mg/ℓ	1.6	5.0
Ammonia-nitrogen mg/ℓ	329.	1.1
Nitrite-nitrogen, mg/ℓ	0.6	1.2
Nitrate-nitrogen, mg/ℓ	0.6	342.
Thiocyanate, mg/ℓ	2.2	0.01
Cyanate, mg/ℓ	32.	0.5
Cyanide, Refractory, mg/ℓ	0.5	0.2
Cyanide, Free, mg/ℓ	0.5	0.01
Cyanide, Total, mg/ℓ	1.	0.2
Chemical Oxygen Demand, mg/ℓ	110.	56.
Phosphate, mg/ℓ	0.4	4.6
Phenol, mg/ℓ	0.06	<0.006
Total Suspended Solids, mg/ℓ	76.	14.
Volatile Suspended Solids, mg/ℓ	13.	7.
Total Dissolved Solids, mg/ℓ	3400.	5700.

*Values averaged over the 87-day test period.

**From cooling-tower hot well of blast-furnace recycle-water system.

TABLE 4. RBC DEMONSTRATION TEST DISTRIBUTION OF AMMONIA-, NITRATE-, AND NITRATE-NITROGEN IN THE RBC STAGES

	Concentration, mg/ℓ			
	Influent	Stage 1	Stage 2	Stage 3 (Effluent)
NH_3-N	329.	138.	22.	1.1
NO_2-N	0.6	46.	35.	1.2
NO_3-N	0.6	157.	279.	342.

phosphate content increased because phosphoric acid was added to the Na_2CO_3 solution to provide phosphorus.

The distribution of NH_3-N, NO_2-N, and NO_3-N in the three stages is shown in Table 4. Note the decrease in NH_3-N and NO_2-N and the increase in NO_3-N in stages 1 through 3. The higher concentration of NH_3-N in stages 1 and 2 inhibited the conversion of NO_2^- to NO_3^- by Nitrobacter and NO_2^- accumulated.4) The distribution of the various forms of nitrogen in the RBC influent and effluent is shown in Table 5. The data in the table show that 96 percent of the nitrogen present in the RBC influent is derived from NH_3 (3% from cyanate and 1% from nitrite, nitrate, and cyanide), whereas 97 percent of the nitrogen in the RBC effluent is present in the form of nitrate (2% of the nitrogen is incorporated into the biomass).

EFFECT OF MEDIA SPACING

Two types of plastic media are available from an RBC manufacturer--standard-density with about 7/8-inch spacing between the disks and high-density or nitrifying media with about 1/2-inch spacing. The standard-density media are normally used in applications in which a thick biomass is developed such as in the conversion of carbonaceous materials in a municipal-sewage treatment plant. Because nitrifying bacteria do not develop as thick a biomass as organisms that convert carbonaceous materials, the closer-spaced media can be used for nitrification. The nitrifying media provide 50 percent more surface area per given shaft length than standard-density media; that is, a 26-foot-long shaft with 12-foot-diameter disks will provide 100,000 and 150,000 square feet (ft^2) of surface area with standard-density and nitrifying media, respectively.

The pilot RBC came equipped with standard-density media and these were used in cells 1, 2, and 3 during the entire test program. To determine whether the nitrifying media are compatible with blast-furnace recycle water, the media in cell 4 were replaced with nitrifying media about halfway through the pilot study. The nitrification rates obtained with the nitrifying media were comparable to rates achieved with the standard-density media. At the end of the pilot study, sheets of standard-density and nitrifying media were removed, and both were found to have a uniform coating of biomass over the entire surface of the sheet. Therefore, the nitrifying media performed satisfactorily and are recommended for use in a full-scale facility.

SHAFT-WEIGHT INCREASE AND POWER CONSUMPTION

The shaft weight was measured about twice a month by using load cells. The load cells were placed under the two shaft bearings, and the shaft weight was measured with the disks rotating and static. The cumulative shaft-weight over an 11-month period is shown in Figure 6; both rotating and static weights are plotted. The weight of the disks and shaft increased steadily from 5200 to 6800 pounds over the 11-month period. For about half the period, cell 4 was operated with standard-density media, then with high-density nitrifying media which contain 50 percent more sheets of plastic per given length of shaft than standard-density media.

TABLE 5. RBC DEMONSTRATION TEST DISTRIBUTION OF NITROGEN (weight percent)

	Influent	Effluent
NH_3-N	96.20	0.32
NO_2-N	0.16	0.36
NO_3-N	0.19	97.33
SCN-N	0.16	<0.02
CNO-N	3.10	0.05
CN-N	0.19	<0.02
Biomass	-	1.94

TABLE 6. CHEMICAL ANALYSIS OF BIOMASS (Dry Basis)

C, wt %	25.7
H	3.9
N	2.2
P	1.7
Fe	14.8
Ca	2.9
Na	0.7
Volatile Matter	49.4

TABLE 7. COMPARISON OF ELEMENTAL ANALYSIS OF BIOMASS TO THEORETICAL COMPOSITION

	Composition of Volatile Matter wt %	Theoretical Composition wt %
C	52.0	51.7
H	7.8	6.0
N	4.4	12.1
P	3.4	2.6
O (by difference)	32.4	27.6

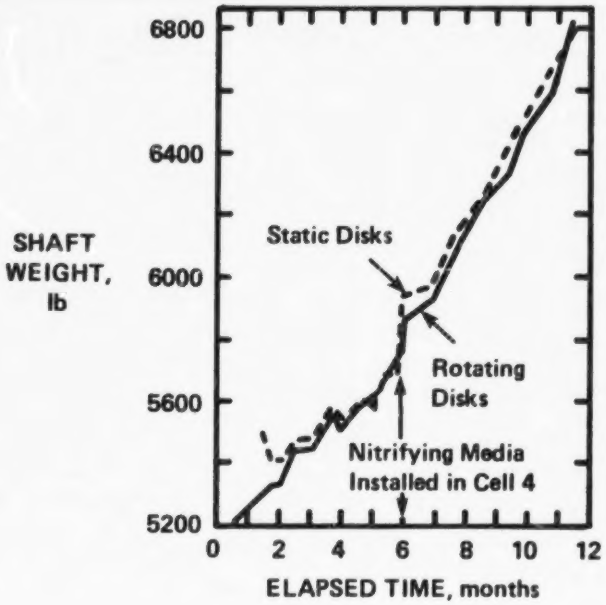


Figure 6 Increase in Pilot RBC-Shaft Weight

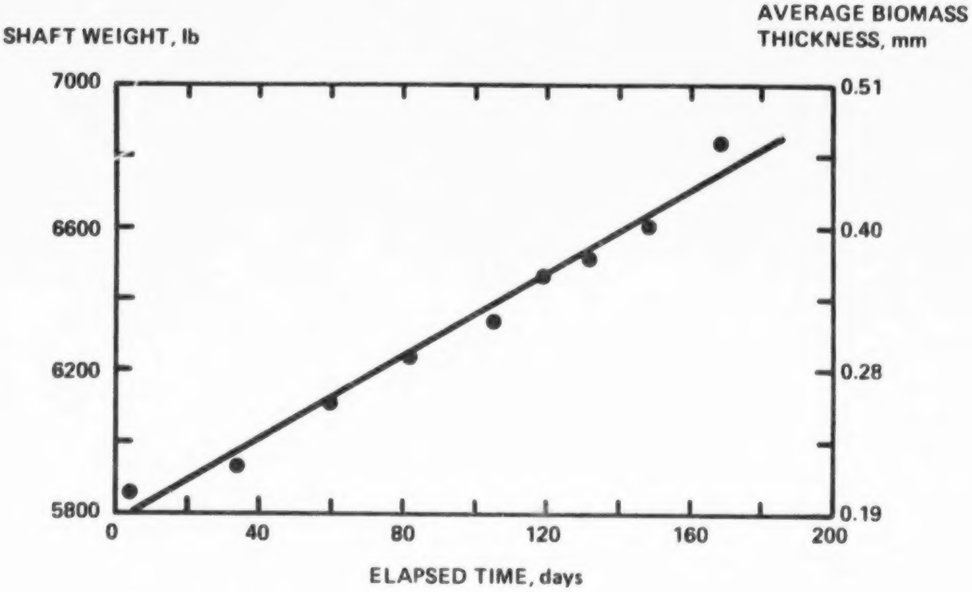


Figure 7 Shaft Weight With Nitrifying Media in Cell 4 (Weight Measured While Disks Rotating)

The shaft weight increased about 180 pounds because of the extra sheets of media, and this increase is shown in Figure 6. The shaft weight with nitrifying media is plotted in Figure 7 and a line of best fit, which was derived by using least-squares linear regression, is shown.

Also indicated on Figure 7 is the average biomass thickness calculated from the weight increase and surface area of the media. Cell 1 media had the thickest biomass, estimated to be about 1 millimetre (mm), but only an average thickness can be calculated from shaft weight because all four cells are on the same shaft.

The curves in Figure 6 show a steady increase in biomass growth during the 11-month period, with no sign of a leveling off in weight gain. Reports in the literature,5,6) indicate a maximum nitrifier thickness of about 2 mm when the biomass growth rate and biomass sloughing rate are balanced. Therefore, at the growth rates shown in Figure 7, the shaft weight would show a steady increase for an additional two or more years. A steady increase in the nitrification rate would not be expected because photomicrographs of the biomass showed that the viable organisms are mostly at the surface of the biomass (see section on biomass characterization).

The power consumption of the electric motor that rotated the shaft was measured daily with a voltmeter and an ammeter. The average power consumption remained fairly constant at about 1500 watts and showed no tendency to increase, even though the shaft weight increased about 1600 lb.

CHARACTERIZATION OF BIOMASS

Samples of the biomass were scraped off the disks and the chemical composition was determined, Table 6. The biomass contained 91 percent water, and 49 percent of the dry biomass was volatile. In Table 7 the carbon, hydrogen, nitrogen, phosphous, and oxygen contents of the volatile portion of the biomass are compared with the theoretical composition3) of nitrifying bacteria; except for the nitrogen content the agreement is good.

Samples of the biomass were also sent to the University of Alabama in Birmingham, Department of Biology, for characterization by electron microscopy.7) Electron photomicrographs of the bacteria responsible for oxidizing NH_3 to NO_2^-, Nitrosomonas, and the bacteria that oxidize NO_2^- to NO_3^-, Nitrobacter, are shown in Figures 8 and 9, respectively; note the difference in membrane structures between Nitrosomonas and Nitrobacter.

A small section of media and biomass (about 0.5 square inch) was cut from a disk and electron micrographic cross-sections (3750X) of the biomass were taken at various depths. Figure 10 represents the edge of the biomass farthest from the plastic media, and Figure 11 represents the biofilm closest to the media, intermediate areas were also examined. An overview of all the sections indicates that the population density of healthy, intact bacterial cells appears highest on the outer edge of the biofilm, Figure 10. The amount of cellular debris and degree of cellular disruption appears to increase inward toward the disk surface. This is probably due to the lack of availability of nutrients and oxygen on the inside of the film.

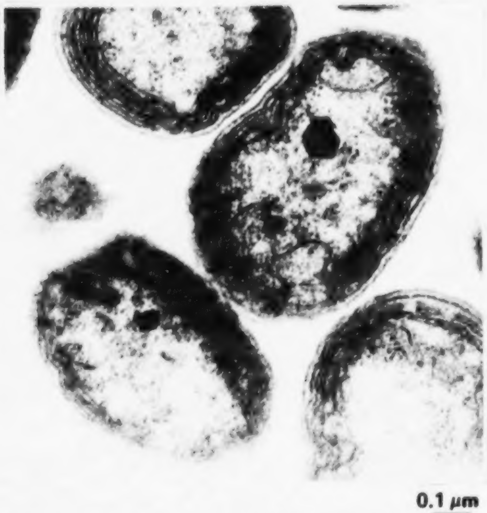


Figure 8. Electron Micrograph of RBC Biomass Nitrosomonas Europaea

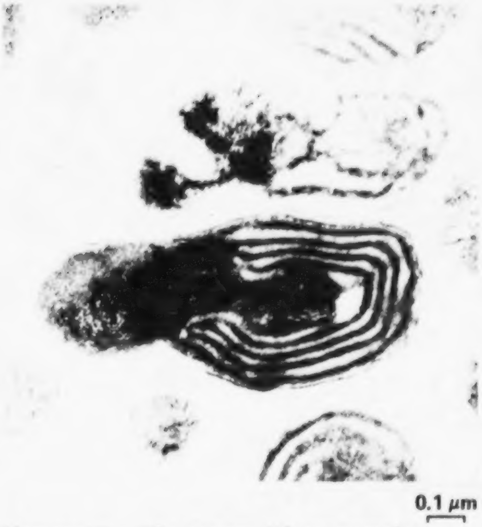


Figure 9. Electron Micrograph of RBC Biomass Nitrobacter

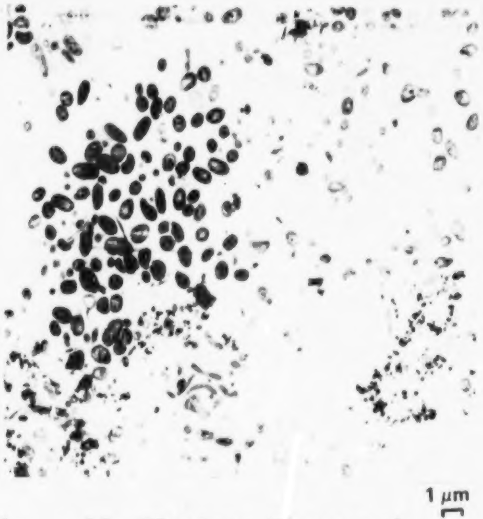


Figure 10. Electron Micrograph of RBC Biomass Section Farthest from Media

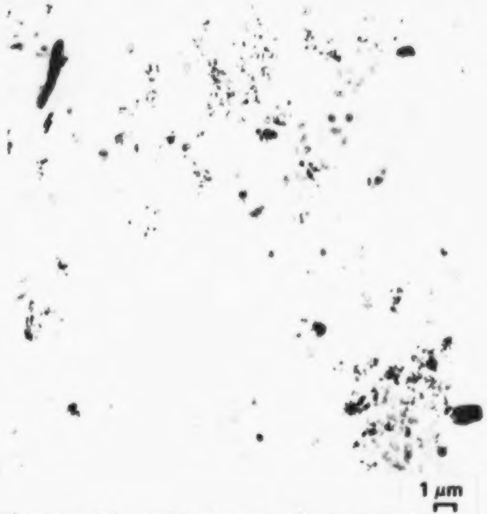


Figure 11. Electron Micrograph of RBC Biomass Section Closest to Media

CLARIFICATION OF RBC EFFLUENT

Over the period of the pilot study, the blast-furnace recycle-water blowdown contained about 100 mg/ℓ of total suspended solids (TSS) and about 15 mg/ℓ of volatile suspended solids (VSS), whereas the effluent from the third stage contained about 26 and 12 mg/ℓ of TSS and VSS, respectively. In the event that the RBC effluent should require further clarification, clarifier and pressure-filtration tests were conducted.

Because the suspended-solids content of the RBC effluent is variable, a clarification test was conducted over a six-week period. During this period, the effluent from cell 3 was diverted to a small clarifier constructed from a 55-gallon drum. During this period cells 1, 2, and 3 were operated in series (influent → cell 1 → cell 2 → cell 3 → clarifier → sewer) and after steady-state operation was achieved, samples of the RBC influent and effluent from each cell and the clarifier overflow were analyzed for TSS and VSS. The results of this test are summarized in Table 8. The average TSS concentration in the RBC influent was 170 mg/ℓ, the TSS in the RBC effluent (stage 3) was 13 mg/ℓ, and the clarifier overflow contained 6 mg/ℓ of TSS; no flocculating polymer was added during this test.

Pressure filtration was also investigated; the tests were conducted in a 4-litre Dicalite bomb filter press with and without filter aids. The results of the pressure-filtration tests are summarized in Table 9. The tests demonstrated that a filtrate containing less than 5 mg/ℓ of TSS can be obtained at a high filtration rate of about 1.4 gallon per minute per square foot for an 8-hour cycle.

It was found that the RBC effluent can be easily clarified. The choice of a specific clarification method will be a function of the TSS discharge limit and the type of sludge desired.

EQUIPMENT-FAILURE SIMULATION

During the pilot study, the RBC and ancillary equipment were carefully maintained and operated; consequently there were no equipment failures of long duration. In a full-scale facility with 10 or more RBC units, failures of various systems lasting 12 to 24 hours may be possible. Possible areas of failure are (1) loss of the sodium carbonate solution pumps, (2) loss of disk rotation, and (3) loss of influent flow. These possible conditions were simulated to determine their effect on the biomass and nitrification, especially how the biomass recovered from the shock caused by the failure.

The sodium carbonate solution pump was shut off for 24 hours to one cell of the RBC, while influent flow and disk rotation were maintained. The pH of the water in the RBC cell dropped from the normal 7.2 to 6.4 and the nitrification rate decreased about 50 percent during the outage. After the pump was restarted, about 72 hours were required for the nitrification rate to return to normal. The 24-hour outage was probably a "worst case" simulation because the pH dropped significantly within one hour of the pump

TABLE 8. CLARIFICATION OF RBC EFFLUENT

Average Solids Concentration, mg/ℓ									
RBC Influent		Stage 1		Stage 2		RBC Effluent (Stage 3)		Clarifier Overflow	
TSS*	VSS**	TSS	VSS	TSS	VSS	TSS	VSS	TSS	VSS
170	16	30	12	16	5	13	6	6	2

*TSS - Total Suspended Solids
**VSS - Volatile Suspended Solids

TABLE 9. PRESSURE-FILTRATION TESTS ON RBC EFFLUENT*

Test No.	Test Conditions		Filter Aid**	Solids Concentration, mg/ℓ				Filtration Rate***	
				Before Filtration		After Filtration			
	Pressure, psig	Temp., °F		TSS	VSS	TSS	VSS	4-hr Cycle, gpm/ft^2	8-hr Cycle, gpm/ft^2
1	5	58	Superaid	20	9	8	2	0.41	0.24
2	5	74	Superaid	18	9	11	7	0.80	0.152
3	5	70	Speedplus	10	6	<0.5	<0.5	1.35	0.80
4	5	75	Speedplus	14	8	2	2	2.19	1.37
5	5	75	5000	41	11	6	4	1.89	1.07
6	5	58	5000	20	9	4	4	0.62	0.35

*Using 4-litre Dicalite filter press.
**Filteraids (Dicalite, Grefco, Inc.):
- Superaid - low clarity, relative-flow-rate rating 1 (fast)
- Speedplus - medium clarity, relative-flow-rate rating 7
- 5000 - high clarity, relative-flow-rate rating 20.5 (slow)

***Extrapolated to 50 psig operation.

failure and in a full-scale facility a pH alarm would alert the operator to the problem.

The disk rotation was stopped for 23 hours, and about every 6 hours the disks were rotated for four revolutions to keep the biomass moist (the biomass will die if allowed to dry out). During the stoppage, the alkalinity, pH, and NH_3-N all increased because of loss of nitrification, but the effect was temporary and nitrification returned to normal after disk rotation was resumed.

The flow to one of the cells was stopped for 36 hours, while normal rotation and pH control were maintained. Once residual NH_3 in the cell was converted, nitrification ceased but resumed immediately when the flow was restarted. Therefore, depriving the biomass of any food for 36 hours does not appear to harm the bacteria. During the demonstration test, the final stage received very little NH_3 for over a week with no apparent damage to the biomass, which confirms the results of this failure-simulation test.

CONCLUSIONS

1. The pilot RBC successfully treated blowdown from the Lorain-Cuyahoga Works blast-furnace recycle-water system. During an 87-day demonstration test, the NH_3-N concentration was reduced from 329 to 1 mg/ℓ.

2. Both standard-density media and closely spaced high-density nitrifying media were tested and both were satisfactory.

3. The shaft weight increased 1400 lb due to biomass growth, but the power requirement to rotate the disks did not increase.

4. The RBC effluent contained about 25 mg/ℓ of TSS and could be further clarified by filtration or sedimentation.

5. Various equipment failures were simulated (loss of alkalinity control, disk rotation, and influent flow) with no lasting effects on the biomass.

REFERENCES

1. The Making, Shaping, and Treating of Steel 9th edition, H. E. McGannon, editor, United States Steel Corp., Pittsburgh, 1971.

2. L. D. Benefield and C. W. Randall, Biological Process Design for Wastewater Treatment, Prentice-Hall, Inc., Englewood Cliffs, New Jersey, 1980, p. 218.

3. Process Design for Nitrogen Control, United States Environmental Protection Agency, October 1975, pp. 3-2, 3-3, and 4-49.

4. A. C. Anthonisen, R. C. Loehr, T. B. S. Prakasam, and E. G. Srinath, "Inhibition of Nitrification by Ammonia and Nitrous Acid," Journal Water Pollution Control Federation, Vol. 48, No. 5, May 1976, pp. 835-852.

5. C. P. C. Poon, et al., "Upgrading with Rotating Biological Contactors for Ammonia Nitrogen Removal," Journal Water Pollution Control Federation, Vol. 53, No. 7, July 1981, p. 1162.

6. K. Ito and T. Matsuo, "The Effect of Organic Loading on Nitrification in RBC Wastewater Treatment Processes," Proceedings, First National Symposium/Workshop on Rotating Biological Contactor Technology (Champion, Pennsylvania, February 1980), Vol. II, University of Pittsburgh, June 1980, p. 1169.

7. J. J. Gauthier and D. D. Jones, University of Alabama in Birmingham, Department of Biology, private communication, 1981.

The material in this paper is intended for general information only. Any use of this material in relation to any specific application should be based on independent examination and verification of its unrestricted availability for such use, and a determination of suitability for the application by professionally qualified personnel. No license under any United States Steel Corporation patents or other proprietary interest is implied by the publication of this paper. Those making use of or relying upon the material assume all risks and liability arising from such use or reliance.

BLAST FURNACE - RECYCLE SYSTEM

SIDE STREAM SOFTENING

SUMMARY OF FULL SCALE TRIAL

BY

LEONARD D. WISNIEWSKI
ASSISTANT DIRECTOR - WATER
ENVIRONMENTAL CONTROL

AND

RICHARD L. NEMETH
ASSISTANT SUPERINTENDENT
ENVIRONMENTAL CONTROL

REPUBLIC STEEL CORPORATION
CLEVELAND, OHIO 44101

NOVEMBER, 1982

The work described in this paper was not funded by the U.S. Environmental Protection Agency. The contents do not necessarily reflect the views of the Agency and no official endorsement should be inferred.

ABSTRACT

Republic Steel Corporation's Cleveland District has undertaken a program to reduce blast furnace recycle system blowdown to volume levels that can either achieve regulatory requirements or be disposed of via quenching and evaporation on blast furnace slag. This is a potential alternate to the treatment of blast furnace blowdown using alkaline-chlorination treatment. It will be necessary to remove scale forming constituents from the recirculating waters to prevent harmful buildup throughout the recycle system as the cycling is increased. Republic is attempting to accomplish this by investigating the effectiveness of "side-stream" softening a portion of the total recycle volume.

This paper details the results of the work conducted to date on a trial softening program at its 5 & 6 Blast Furnace Recycle System at the Cleveland District steelmaking facility. Included is a description of the modified treatment system and a summary of the water chemistry softening results. A summary which compares the system's discharge loads to the recently promulgated Best Available Technology (BAT) effluent limitation guidelines is also included. This paper is a followup to a paper presentation made by the same authors last year at the U.S. EPA Symposium on Iron and Steel Pollution Abatement Technology for 1981, which dealt with the efforts to minimize Cleveland's 5 & 6 Blast Furnace recycle system blowdown rate to below BAT levels.

BACKGROUND

BLOWDOWN MINIMIZATION

Recycle water systems for gas cleaning and cooling were installed at both Cleveland District Blast Furnace complexes to conform with Best Practicable Technology (BPT) requirements. These systems were designed to operate at blowdown rates of 1,000-1,200 gpm, enabling them to meet these guidelines. It was apparent that these design criteria (the high blowdown rates) could not achieve compliance with proposed Best Available Technology (BAT) limitations. The options available dictated the necessity to reduce blowdown to a more manageable rate, thereby minimizing future capital expenditure and operating costs to meet these BAT regulations.

The immediate concern in efforts to reduce the blowdown rates centered around elimination of extraneous water infiltration to the recycle systems. These sources were the cause of hydraulic imbalance which required the elimination of water from the systems for hydraulic rather than water chemistry reasons. The fact that these were retrofit systems to existing facilties complicated the task. However, results of identifying and systematically eliminating sources of extraneous water culminated in the ability to hydraulically operate one of these systems, the 5 & 6 Blast Furnace Recycle System, with a sustained very low blowdown rate. Although unresolved problems with hydraulic balance of this system remain, the sources have been identified and can managed be either physically or administratively.

Figure 1 illustrates the results of blowdown reduction, tracking the system from January, 1980 to September, 1982. The apparent increase after November, 1981 was due to a decrease in iron production which reflected an increase in the blowdown rate (gallons per ton) while the actual blowdown rate (gallons per minute) remained relatively constant. The extraneous water resulting in the blowdown volume was related to the blast furnace in operation and should be resolved when this furnace is taken down for rebuild.

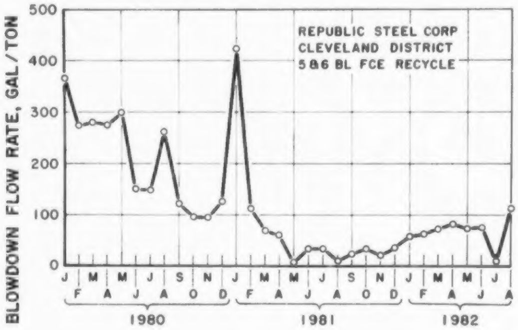


Figure 1. Republic Steel Cleveland District - Nos. 5 & 6 Blast Furnace Recycle System - Blowdown Flow by Month.

Another alternative to meet BAT limitations was to not discharge blowdown from the recycle system. No discharge, of course, would eliminate the concern for constituent limitations. No discharge does not mean zero blowdown. If blowdown rates are minimal, methods for blowdown disposal become very viable alternates to discharge treatment. Water evaporation from blast furnace slag quenching or pelletizing could then provide adequate disposal for blowdown from a very tight system.

Water chemistry became a factor of significant impact, once having resolved the hydraulic needs of the system. As demostrated by deposit analyses shown in Figure 2, continued operation of this system with very low blowdown showed a marked increase in the calcium carbonate concentration. Applying patented chemical treatment to cope with this potential did provide for a degree of success, however, sustained operation with this scheme was still unproven. For this reason a study in the use of side stream water softening to control system hardness was undertaken in 1981.

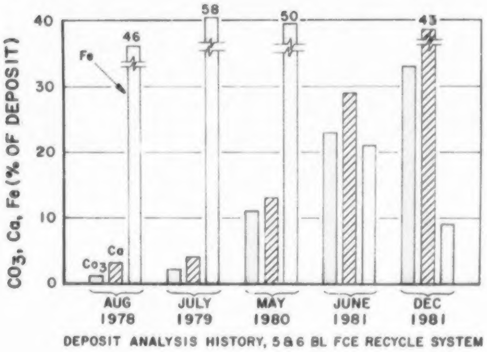


Figure 2. Republic Steel Cleveland District - Nos. 5 & 6 Blast Furnace Recycle System - Deposit Analysis History.

PILOT STUDY

The U.S. EPA Mobile Pilot Treatment Plant was utilized to investigate various softening modes on a 5-6 gpm side stream to determine the feasibility and cost effectiveness of side stream softening to control system hardness. This method of controlling calcium carbonate scaling potential was a technology transfer from closed, recirculating cooling systems to a blast furnace recycle system. Results of the trial affirmed this potential. Trial results demonstrated the ability to sucessfully soften the blast furnace recycle water by several means, from classic lime-soda ash softening to simply elevating the pH by caustic soda addition. The pilot studies also affirmed that remixing of softened water with unsoftened recycle water generated continued softening reactions and sedimentation in the mixed stream, a situation which must be considered in the future design of a side-stream softening system.

Questions concerning practicality, operating costs and overall effect of side stream softening on the entire recycle system had to be resolved. The decision was made to expand the investigations to a full scale trial to provide answers to these questions.

FULL SCALE TRIAL

OBJECTIVES

A major concern in the full scale softening trial was the control and monitoring of calcium and total hardness, these being the most impactive constituents for system problems. Softening potential of this water had already been established, so the overall effect of continuous side stream softening to maintain a lowered system hardness was of significant interest. It was necessary to observe what effects this scheme had on equipment at various stages of the system, and if other constituents in the water would indicate additional problems.

The cost of side stream softening had to be more precisely determined than those costs projected by the pilot plant study. These determiantions had to be established within the constraints of existing equipment at the water treatment plant. A staff from Republic's Research Center was utilized to operate, monitor and evaluate the softening trial.

PHYSICAL DESCRIPTION

One of the two 90' diameter clarifiers was modified for use as a softener. No. 2 Clarifier was selected because of it's proximity to the influent stream, which allowed for remixing of the softened water with the influent stream ahead of the other clarifier. Any precipitation due to continued post-mix softening would be settled out in either clarifier and removed along with the settled solids at the vacuum filters. Clarifier discharge piping had to be modified to redirect softener effluent from the hot well of the recycle system cooling tower to the influent trench as shown in Figure 3. This was accomplished by adding a second discharge pipe from the overflow launder of the softener-clarifier to the influent trench, and blanking off the overflow launder discharge to the hot well as shown in Figure 4. These modifications were made so No. 2 Clarifier could be quickly returned to a full stream clarifier if it became necessary to abort the trial due to a malfunction of No. 1 Clarifier.

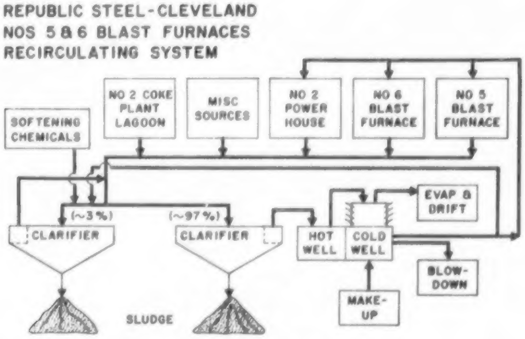

REPUBLIC STEEL-CLEVELAND
NOS 5 & 6 BLAST FURNACES
RECIRCULATING SYSTEM
SOFTENING CHEMICALS
NO 2 COKE PLANT LAGOON
MISC SOURCES
NO 2 POWER HOUSE
NO 6 BLAST FURNACE
NO 5 BLAST FURNACE
(~3%)
(~97%)
CLARIFIER
CLARIFIER
HOT WELL
COLD WELL
EVAP & DRIFT
BLOW-DOWN
MAKE-UP
SLUDGE

Figure 3. Republic Steel Cleveland District - Nos. 5 & 6 Blast Furnace Recycle System - Flow Schematic for Side Stream Softening Trial.

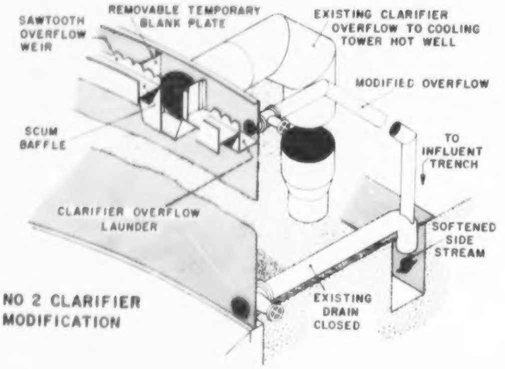

SAWTOOTH OVERFLOW WEIR
REMOVABLE TEMPORARY BLANK PLATE
EXISTING CLARIFIER OVERFLOW TO COOLING TOWER HOT WELL
MODIFIED OVERFLOW
SCUM BAFFLE
TO INFLUENT TRENCH
CLARIFIER OVERFLOW LAUNDER
SOFTENED SIDE STREAM
NO 2 CLARIFIER MODIFICATION
EXISTING DRAIN CLOSED

Figure 4. Republic Steel Cleveland District - Nos. 5 & 6 Blast Furnace Recycle System - No. 2 Clarifier Modification for Side Stream Softening Trial.

The next concern was to develop a method to measure the side stream flow which was to be regulated by positioning No. 2 clarifier shut off gate. A temporary flume, similar to a Palmer-Bowles type, was constructed and inserted into No. 2 Clarifier influent launder. This flume, although crude, was an effective primary flow measuring device. The method for softening was simply pH elevation by addition of caustic soda (sodium hydroxide). The method was selected for simplicity, as liquid caustic was readily available in bulk, and feed could be easily controlled and measured. As shown in Figure 5, caustic was fed directly from a bulk tank truck through a regulated value to provide the desired feed rate. The feed rate was measured manually at the feed point in the clarifier influent launder.

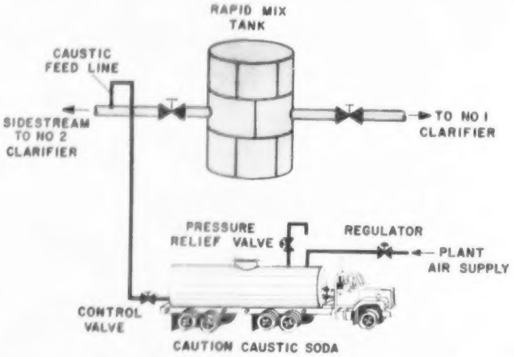

RAPID MIX TANK
CAUSTIC FEED LINE
SIDESTREAM TO NO 2 CLARIFIER
TO NO I CLARIFIER
PRESSURE RELIEF VALVE
REGULATOR
PLANT AIR SUPPLY
CONTROL VALVE
CAUTION CAUSTIC SODA

Figure 5. Republic Steel Cleveland District - Nos. 5 & 6 Blast Furnace Recycle System - Caustic Soda Feed System for Side Stream Softening Trial.

CONSTRAINTS

Numerous constraints had to be reconciled both prior to and during the trial period. Logic dictated not to attempt this experiment during the winter, considering the physical characteristic of 50% caustic soda and its solution freeze point of 54°F. During these severe economic times, funding of such a project can also be restrictive. Credit district and corporate management for authorizing funds for this program. The modifications required for the trial interfered with scheduled clarifier maintenance and imposed a time constraint.

During this trial, only No. 5 blast furnace was in operation. Of the two furnaces, No. 5 caused the most severe hydraulic imbalance and unsteady operation since its general condition was less than ideal as it concludes its current campaign. Therefore, general system stability (water flows, blowdown, water chemistry) was somewhat erratic prior to, and during the trial. Coupled to the normal operating problems inherent to any blast furnace and water treatment system, considerable effort was necessary to maintain system tightness sufficiently to proceed.

The modifications to perform the trial, though adequate, were far from ideal. Flow control of the side stream and the caustic feed required close monitoring and constant attention. Calculated caustic feeds were soon discarded in favor of caustic feed adjustment to obtain desired pH in the softener-clarifier. Monitoring of the trial under these constraints required many man hours and the efforts of several people.

Chemical constraints of the system were present. It was unknown at what pH the entire recycle system would stabilize while the softening clarfier was maintained at the pH level necessary to sustain the softening reaction. The potential existed for acid to be fed to the recycled water for pH adjustment, because of discharge requirements and for cyanide control. The initial softening effect of pH elevation in the system had to be addressed carefully so as not to cause deposition throughout the system.

TRIAL PROCEDURE

Previous data while operating the system at very low blowdown rates prior to softening would be used as the base of comparison. System hardness was reduced by increasing blowdown to minimize the effect of initial softening and to reduce both the time and the caustic required. The blowdown was then reduced as the trial began to allow concentrating of the hardness constituents. The trial proceeded by softening a 250 gpm influent side stream at a pH of 10.5, then at a pH of 9.5, then back to a pH of 10.5. Next, a clarified and cooled water side stream of 150 gpm was softened at a pH of 10.5. Without sophisticated pH control equipment, pH values varied somewhat throughout each trial phase. However, control was adequate enough to demonstrate the principle and observe the results.

TRIAL MONITORING

It was first necessary to monitor certain physical parameters to keep on track with the trial procedures. Calibration of the influent flume fo-flow measurement allowed for monitoring and adjusting flow to maintain a constant side stream flow. Measuring caustic feed indicated consumption rates and helped to regulate softener pH. Desired softener pH determined caustic feed. Continuous monitoring of system flow, make-up flow and blowdown flow indicated the degree of system tightness.

The next monitoring requirement dealt with water chemistry, which included monitoring for several constituents at many points throughout the system. Temperature, conductivity, pH, alkalinity, calcium hardness, total hardness, chloride concentration and turbidity were monitored daily at five points throughout the system. This data would indicated the degree of success or failure of the project objectives.

Last came observations of the overall effect on the physical system. This was accomplished by frequent inspections of strategically located deposition coupons. Before and after inspections of the gas cooler were conducted to determine if there were any major indications of potential problems.

RESULTS

The trial began on June 8, 1982 and proceeded in four modes until August 2, 1982. System history as shown in Figure 6 demonstrates that at the comparable BAT blowdown rate of 70 gallons per ton, the system total hardness was approximately 750 mg/l. Data collected during the softening trial showed a hardness level of 500 mg/l could be maintained at a blowdown range of between 3.5-7.0 gallons per ton. Historical data indicated that at this very low blowdown rate, total hardness without softening was over 1,000 mg/l.

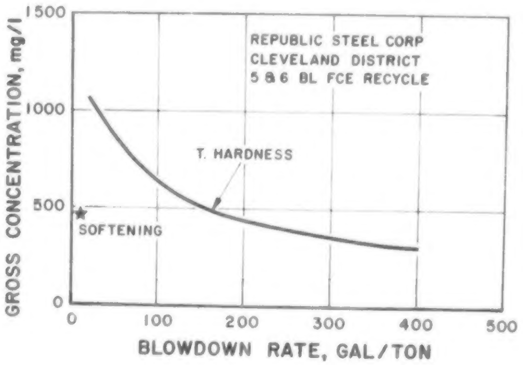


Figure 6. Republic Steel Cleveland District - Nos. 5 & 6 Blast Furnace Recycle System - Total Hardness as a Function of Blowdown Rate (January, 1981 - August, 1982), including Side Stream Softening Trial.

During the trial period, system pH remained at 8.0 to 8.2 with no significant changes in pH occuring at any time. Inspection of deposition coupons throughout the system showed that no significant deposits occurred during the trial. The overflow weirs of the softener-clarifier did show a white scale deposit that did not pose a problem during the trial. Concurrently, vacuum filter operation appeared more effective, with media life doubling. It has been theorized that high system hardness may cause reduced filter-bag life because of premature blinding of the media fibers.

A post-trial inspection of the blast furnace gas cooler showed no signs of increased depostion, and general system cleanliness remained very good. The net reduction of total system hardness was optimum when the 250 gpm side stream was softened by pH elevation to 10.5, when system hardness was maintained at the 300-400 mg/l range. Operating the side stream at a pH of 9.5 caused a slight increase in system hardness to the 400-500 mg/l range. Reduction of the side stream to 150 gpm and operating at a pH of 10.5 resulted in system hardness of 500-600 mg/l. Calcium hardness in the recycle system throughout the trial for the most part remained in a 130-230 mg/l range.

CONCLUSION

This full scale trial has conclusively indicated that side stream softening can maintain reduced system hardness in this blast furnace system when operated with blowdown levels significantly lower than BAT rates. Hardness levels in the 300-500 mg/l range have been demonstrated to be manageable with conventional water treatment schemes. This method of side stream softening for hardness control can be viable with a properly designed system. However, the levels of nonprecipitating ions such as sodium and chloride may continue to concentrate to high levels which could subsequently lead to potential corrosive conditions. To date, chloride concentrations up to 2,000 mg/l have been observed without indications of abnormally high corrosion.

FUTURE WORK

There still remains unanswered questions with regards to this trial. The time constraints previously mentioned limited verification of long term effects. A trial running for several months would provide more insight and allow for additional related studies of overall system effects such as deposition, corrosion, scrubber and cooler efficiencies, and effects on other BAT related water constituents such as ammonia, cyanide, phenol, lead, and zinc.

COSTS

The cost of chemical treatment for this side stream softening trial are shown in Figure 7 as compared to current BPT treatment costs and projected alkaline chlorination costs. The current chemical costs are a base line figure which includes clarification and deposit control agent currently in use. The alkaline chlorination costs reflect single and two stage, and air stripping with two stage, as outlined in Pilot Evaluation of Alkaline Chlorination Alternatives for Blast Furnace Blowdown Treatment, Metcalf & Eddy, presented at the U.S. EPA Symposium on Iron and Steel Pollution Abatement Technology for 1981. Costs were calculated in Dollars per Million Gallons Treated (Blowdown or Side Stream) and Dollars per Million Gallons Recirculated, to put them into perspective with BPT treatment costs. These figures indicate that chemical treatment for side stream softening by caustic addition are in the same range as projected costs for alkaline chlorination treatment of blowdown water to attain BAT limitations. Pilot plant studies conducted in 1981 indicate a lower cost for softening by lime and soda ash, which would inhance the chemical cost advantage of side stream softening over alkaline chlorination.

TREATMENT SCHEME	SYSTEM FLOW	TREATMENT STREAM FLOW	COSTS $/MG TREATED	RECIRCULATED
CURRENT BPT	4500	4500	28	28
ALKALINE-CHLORINATION				
SINGLE-STAGE	9000	300	1207	39
TWO-STAGE	9000	300	1253	41
AIR-STRIP W/TWO-STAGE	9000	300	936	30
SIDE-STREAM SOFT				
pH 9.5	4500	250	825	46
pH 10.5	4500	250	1028	57
pH 10.5	4500	150	1000	33

Figure 7. Republic Steel Cleveland District - Nos. 5 and 6 Blast Furnace Recycle System - Treatment Scheme Cost Comparison.

Detailed figures for the capital costs or other operating costs of this side stream softening method of treatment are not available. The total costs of modifications to this recycle system to attain very low blowdown rates were less than $0.2 million, and the costs for the modifications required to run this trial were less than $50,000. The capital costs of alkaline chlorination treatment systems have been estimated by Metcalf & Eddy in their presentation to be $1.2-$1.3 million.

BAT

The 5 & 6 Blast Furnace Recycle System effluent quality approaches the recently promulgated BAT limitations by means of very low blowdown flow without the requirement for additional blowdown treatment. Figures 8-12 show the general long-term trends for the regulated parameters on both a gross concentration and loading basis. Note the loading curves are asymptotically approaching zero for all of the parameters, despite the corresponding increase in respective concentrations. Listed in Table 1 are the BAT Effluent Limitations as promulgated, on May 27, 1982 for this facility.

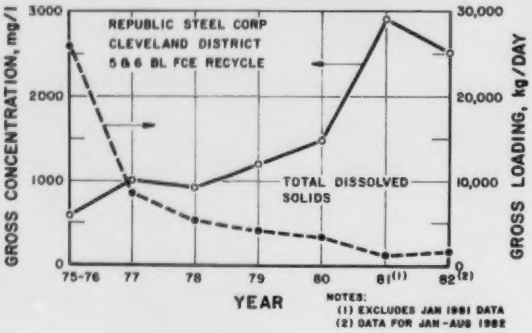


Figure 8. Republic Steel Cleveland District - Nos. 5 & 6 Blast Furnace Recycle System - Total Dissolved Solids gross concentration and gross loading discharge by year.

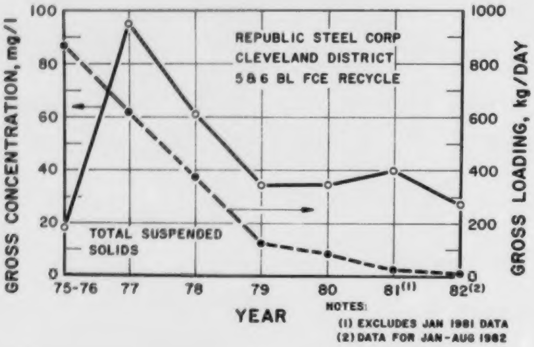
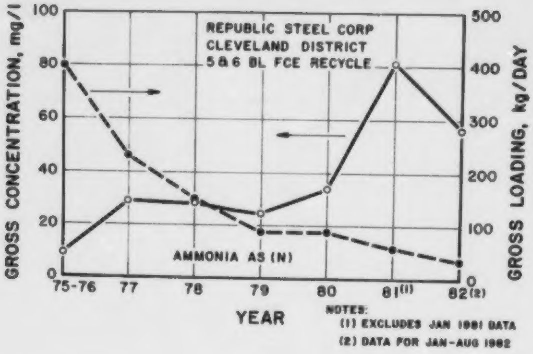


Figure 9. Republic Steel Cleveland District - Nos. 5 & 6 Blast Furnace Recycle System - Total Suspended Solids gross concentration and gross loading discharge by year.

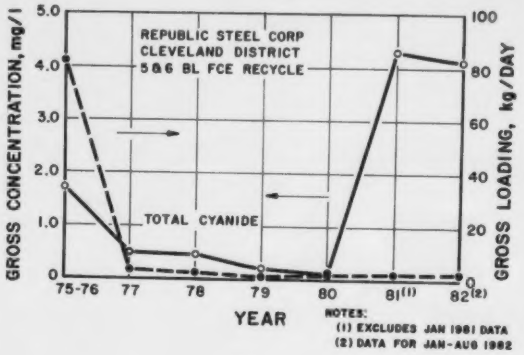
EPA Form 2350-4 (4-80)
(PREVIOUSLY CIN EPA FORM 247)
TYPING GUIDE SHEET

BEGIN FIRST LINE OF TEXT HERE
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD: BEGIN SECTIONS HERE



NOTES:
(1) EXCLUDES JAN 1981 DATA
(2) DATA FOR JAN-AUG 1982

Figure 10. Republic Steel Cleveland District - Nos. 5 & 6 Blast Furnace Recycle System - Ammonia gross concentration and gross loading discharge by year.



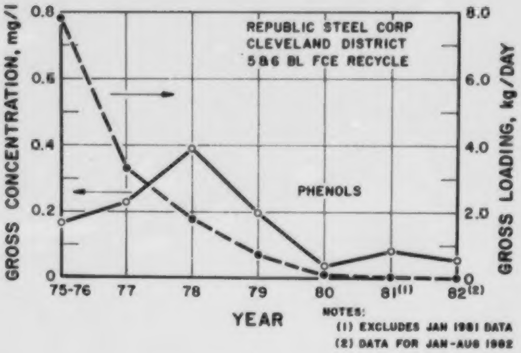
NOTES:
(1) EXCLUDES JAN 1981 DATA
(2) DATA FOR JAN-AUG 1982

Figure 11. Republic Steel Cleveland District - Nos. 5 & 6 Blast Furnace Recycle System - Total Cyanide gross concentration and gross loading discharge by year.

BEGIN LAST LINE OF TEXT
3/8"
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS

PAGE NUMBER
EPA Form 2350-4 (4-80)
(PREVIOUSLY CIN. EPA FORM 287)
TYPING GUIDE SHEET

BEGIN FIRST LINE OF TEXT HERE
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD: BEGIN SECTIONS HERE



NOTES:
(1) EXCLUDES JAN 1981 DATA
(2) DATA FOR JAN-AUG 1982

Figure 12. Republic Steel Cleveland District - Nos. 5 & 6 Blast Furnace Recycle System - Phenol gross concentration and gross loading discharge by year.

6-1/2"

TABLE 1.
BAT EFFLUENT LIMITATIONS

Constituent	Monthly Average*	Daily Maximum*
Suspended Solids	132	398
Ammonia(N)	15	44
Cyanide(T)	1.5	2.9
Phenol (4AAP)	0.15	0.29
Lead (T)	0.37	1.11
Zinc (T)	0.44	1.34

*Gross loads (Kg/day)

Comparing the monthly average effluent limitations as shown in Table 1 to the long-term (yearly) average loading data as shown in Figures 9-12, the system should achieve the BAT limitations for suspended solids and phenols and approach these limitations for ammonia and cyanide. Lead and zinc loading comparison to BAT could not be made since this data had not been collected. It is possible that BAT could be achieved with the correction of the existing hydraulic problem in the system. However, blowdown levels would have to be controlled below 20 gallons per ton to assure compliance of the BAT regulations based upon alkaline-chlorination. A method to ensure this blowdown level will be installed at No. 6 Blast Furnace by utilizing recycle system water as make-up to a slag pelletizing operation. Republic expects that 30 gallons per ton can be evaporated by this operation and thus eliminate the recycle system discharge.

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

PAGE NUMBER
EPA Form 2350-4 (4-80)
(PREVIOUSLY CIN. EPA FORM 287)
TYPING GUIDE SHEET

BEGIN FIRST LINE OF TEXT HERE
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD: BEGIN SECTIONS HERE

ACKNOWLEDGEMENTS

The authors wish to express their appreciation to Messrs. Mark Vanek, Bob Phillips and Bill Mozes of Republic Steel Cleveland District for their work and ingenuity in setting up and maintaining this trial. We would also like to thank Messrs. John Lefelhocz and George Sheppard of Republic Steel's Research Center for their efforts in coordinating and monitoring the trial procedures; and express appreciation for the graphic and preparation support of Messrs. Al Crespo and Tom Medvin and Ms. Bettye Lavender. Lastly, we would like to acknowledge Mr. Mitch Kassouf of Betz Laboratories for his help in providing the many services of his company during this trial.

6-1/2"
9-1/8"
BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

EPA Form 2350-4 (4-80)
(PREVIOUSLY CIN. EPA FORM 287)
TYPING GUIDE SHEET

The work described in this paper was not funded by the U.S. Environmental Protection Agency. The contents do not necessarily reflect the views of the Agency and no official endorsement should be inferred.

COSTS OF PRE-TREATMENT OF COKE-PLANT EFFLUENTS

by: J. Ganczarczyk, Professor of Civil Engineering
University of Toronto, Toronto, Ont. M5S 1A4
(416) 978-3141, and

M. Kelleher, Consulting Engineer,
MacLaren Engineers Inc., Toronto, Ont. M5E 1E7
(416) 365-7337

ABSTRACT

One of the most common strategies for pre-treatment of coke-plant effluents consists of wastewater equalization, followed by ammonia stripping. Dissolved air flotation is a compact pretreatment method which is worthy of consideration for some applications. The capital and operating costs, and some technological aspects of each of these three operations are examined in this paper.

Equalization, which is practiced at many plants and is always strongly advised prior to biological treatment, is associated with capital cost which varies linearly with the chosen detention period. The operating costs are minimal. It is expected that adequate equalization periods permit some cyanide conversion, good oil and tar removal, and other aging phenomena which could make the wastewater more amenable to biological treatment. Where equalization precedes ammonia stripping, oil removal improves the effectiveness of the free leg of the still.

Dissolved air flotation removes most of the oil and tar and a portion of the COD bearing material from coke plant wastewater. Although it does not perform the function of equalization, dissolved air flotation can be considered for effective oil and tar removal if the space required for adequate equalization is not available. It has relatively low capital costs, and low operating costs.

In comparison to the other pre-treatment methods discussed, ammonia stripping is associated with relatively high capital and operating costs. Removal of lime solids prior to the fixed leg of a conventional still considerably reduces operating costs and improves the efficiency of the unit. Many new ammonia stripping operations use caustic soda for alkaline pH adjustment because of the numerous operating problems associated with the use of lime. However, the operating costs of modified lime systems are less than those of caustic systems for comparable ammonia removal results.

EPA Form 2350-4 (4-80)
(PREVIOUSLY CIN. EPA FORM 287)

TYPING GUIDE SHEET

PRE-TREATMENT OF COKE-PLANT EFFLUENTS

The major objective of the pre-treatment of coke-plant effluents is to make the wastewater more amenable to subsequent biological treatment and - sometimes - advanced physico-chemical treatment. The pre-treatment of coke-plant effluents is unusually complex; there are many pre-treatment methods available, and numerous pre-treatment strategies are practised. Generally, such pre-treatment includes wastewater stream separation or effluent equalization with pre-sedimentation and optional flotation, phenol extraction or sorption, and ammonia removal. Pre-treatment technologies for cyanide removal are less common. The pre-treatment of coke-plant effluents in North America is based on equalization and storage, followed by free and fixed ammonia stripping. This technology is suggested as Alternate 2 of the "best practicable control technology currently available" (BPCTCA), as described by the Effluent Limitation Guidelines for the Iron and Steel Manufacturing Segment of the Steel Industry.*

COST ESTIMATION METHODOLOGY

Costs presented in this paper are in 1981 Canadian dollars. Equalization tank costs were based on average rates for average conditions provided in "Yardsticks for Costing 1981", published by the Canadian Institute of Quality Surveyors. The capital costs of flotation units were budgetary quotations provided by three different manufacturers. The information on the capital and operating costs of ammonia stripping stills was obtained from a number of North American steel companies, manufacturers of ammonia stills, and some literature references on the subject.

EQUALIZATION

Because coking is a batch process, the collection and equalization of coke-plant effluents is a major pre-treatment step. Equalization periods ranging from 0.5 to 7 days are common practice.**

During the equalization/retention operation some conversion of cyanide to thiocyanate takes place. Effective oil and tar removal can also be achieved. These technological features are dealt with in detail elsewhere. In this work, attention was primarily directed to the cost of the required tanks. Their design was based on the following:

---

* U.S. Environmental Protection Agency. Development Document of Effluent Limitation Guidelines and New Source Performance Standards for the Steel Making Segment of the Iron and Steel Industry, EPA-440/1-74-024a, June 1974.

** Ganczarczyk, J.J., Pre-Treatment of Coke Plant Effluents. Chapter 9 Waste Treatment and Utilization. Edited by Moo-Young, M. and Farquhar, C.J., Pergamon Press, Oxford, 1980.

EPA Form 2350-4 (4-80)
(PREVIOUSLY CIN. EPA FORM 287)
TYPING GUIDE SHEET

(i) A flow of 750 m^3/d (198,000 U.S. gal per day). The equalization basins were sized for detention periods varying from one to ten days.

(ii) A single circular reinforced concrete structure was used for each detention period. The use of two structures would be more practical, but would be more expensive for the same equalization capacity, and therefore was not analyzed here.

(iii) Designs were carried out for side water depths of 3.6 m (11 ft.) and 4.6 (15 ft.) for comparative purposes. A freeboard of 0.6 m (2 ft.) was included in each case.

(iv) The basins would be below grade, with the top 1.2 m (4 ft.) above grade, and backfilled with excavated material. If rock or poor soil conditions requiring extensive dewatering were encountered, a buried basin would not be practical, hence the cost of the basin structure has been separated out for discussion purposes.

(v) It was assumed that the wastewater contains 1-2% flotable oil that would flot to the surface of the basin, and that the wastewater contains very little suspended, settleable material, hence assumulations of sludge at the bottom of the basin would not be significant. It was also assumed that skimming equipment might be considered and its costs have been evaluated.

(vi) Pre-aeration or mixing of the contents of the equalization basin were not considered appropriate for this type of wastewater. Both of these operations are used in the pre-treatment of other industrial wastewaters, where the mixing of different wastewater streams is important to simplify subsequent treatment operations. Either operation would interfere with oil and tar removal, which was considered as an important function of the equalization basin.

(vii) For the sake of simplicity, any addition of chemicals to the wastewater to enhance oil and tar removal and/or cyanide conversion was not covered by this analysis.

The estimated costs of equalization basin and skimming equipment are presented as a function of both basin volume and the wastewater detention time in Figure 1. In Figure 2 the estimated costs of the equalization basin and skimming equipment are shown as a function of the basin diameter. A linear regression of these data indicates that for a basin side water depth (s.w.d.) of 3.6 m (11 ft.), the cost of construction of a partially buried equalization basin can be approximated as:

$29,540 + $30 (V)

(where V is the volume of the equalization basin in cubic metres.)

In general, the cost of excavation was between 15 and 20% of the total cost of the equalization basin. The cost of the concrete structure varied approximately linearly with detention time, and can be approximated by the equation:

$47,560 + $24.70 (v).

EPA Form 2350-4 (4-80)
(PREVIOUSLY CIN. EPA FORM 287)
TYPING GUIDE SHEET

Costs estimated for basins with the same capacity, but with a side water depth of 4.6 m (15 ft.) helped to determine the effect of basin depth on costs. The surface area of the deeper basins was somewhat less, but the depths of excavation and wall construction were obviously greater. Up to a 5-day detention period, the cost of basins of equal capacity, with side water depths of 3.6 m and 4.6 m are almost identical. The deeper basin has a cost advantage at longer detention times and is approximately $20,000 less expensive than the shallower basin for a detention time of 10 days. It has the added advantage of requiring slightly less space.

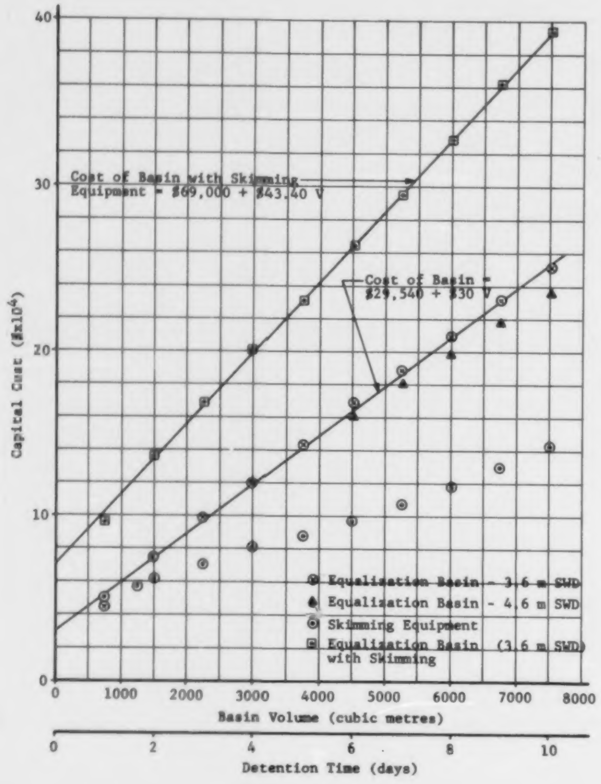


Figure 1 - Capital Cost of Equalization Basins and Skimming Equipment as a function of Basin Volume and Detention Time.

BEGIN FIRST LINE OF TEXT HERE
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD; BEGIN SECTIONS HERE
BEGIN LAST LINE OF TEXT
3/8"
BOTTOM OF IMAGE AREA. OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
EPA Form 2350-4 (4-80)
(PREVIOUSLY CIN. EPA FORM 287)
TYPING GUIDE SHEET

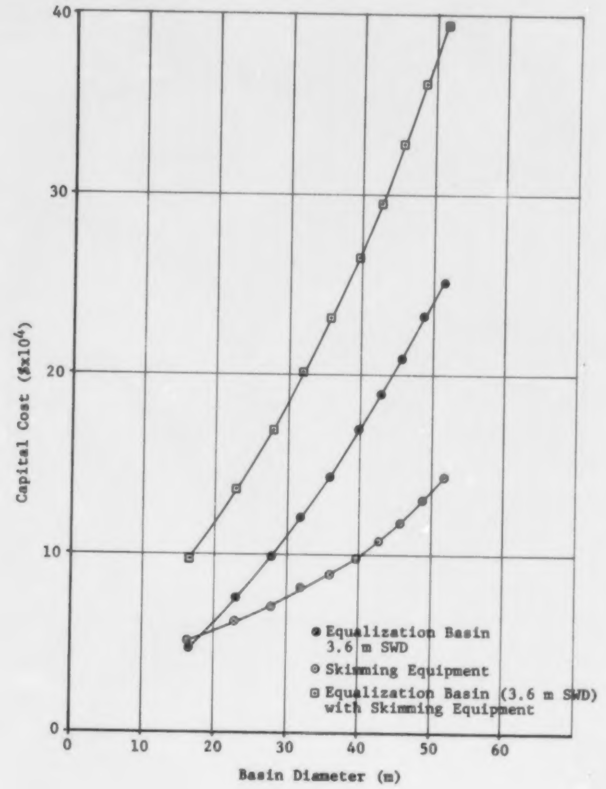


Figure 2 - Costs of Equalization Basin and Skimming Equipment as a Function of Basin Diameter

The cost of the concrete for the base slab of a basin accounts for 40-50% of the total cost of the structure. Other costs vary less significantly with respect to varying depths, hence the extra cost of deeper walls is more than offset by savings in the size of the base slab. In general, deeper equalization basins should be used unless there is some reason why they are not favoured.

The estimated costs of circular skimmers include a drive head, bridge, walkway and handrails, centre column, drive and bridge drive cage, feedwell, two-arm skimmer, scum trough, beach plate, V-notch weir plates and scum baffle plates. These costs increase approximately linearly with detention time. The relationship between cost and basin diameter is approximately linear with a shallow slope ($1910 per metre increase in diameter) for diameters of 36 m or less, and is linear with a steeper slope ($3810 per metre increase in diameter) for diameters greater than 40 m. Cost increases more steeply for larger diameter skimmers, because heavier structures are required for support of the equipment.

EPA Form 2350-4 (4-80)
(PREVIOUSLY CIN. EPA FORM 287)
TYPING GUIDE SHEET

The estimated cost of a circular equalization basin equipped with skimmers can be approximated by the formula:

$69,000 + $43.40 (V).

The cost of the skimming equipment accounts for between 35% and 50% of the total cost of the basins, hence it is a significant portion of the total capital expenditure on this unit operation. Therefore, under normal circumstances, skimming equipment should not be installed on equalization basins until it is proven necessary.

The capital costs of equalization range from $46,800 for a basin of volume 750 m^3 (1-day retention) to $251,200 for a basin of volume 7500 m^3 (10-days retention). This is equivalent to $62.40/$m^3$ for the small basin and $33.50/$m^3$ for the larger basin. The operating costs associated with equalization are minimal. These would consist of $250-$750 per year power costs, if skimming equipment were installed (which is rather uncommon), and some allowance for sludge disposal. If the oily sludge is used as fuel in the coke ovens, sludge disposal could be assumed as cost free. As the technological advantages of wastewater detention times in excess of those required for adequate flow and quality equalization are not yet quantified in detail, a cost-benefit analysis cannot be carried out to compare the technological improvements of longer retention with the increased capital cost of providing this retention.

DISSOLVED AIR FLOTATION

The main purpose of dissolved air flotation would be the removal of oil and tar from weak ammonia liquor prior to both ammonia stripping and the biological treatment plant. It is well known that this removal would improve the effectiveness of ammonia stripping but the extent of this improvement has not yet been quantified to date. It is also well known that oil and tar removal prior to biological treatment would improve the performance of the biological plant. However, it is difficult to quantify the effects of the extent of oil and tar removal on performance of wastewater biological treatment. It was assumed in this study that coke plant wastewaters contain adequate quantities of polymers which would aid dissolved air flotation and also that the oily float would be recoverable. If addition of a coagulant were required, it has been assumed that pickling liquor, which contains ferrous salts, could be added to the effluent prior to flotation to enhance oil removal and achieve some cyanide precipitation at little or no cost. Stripping of volatile substances is expected to be of minor significance.

The capital costs of flotation units were provided by three different manufacturers. A linear regression analysis of the data obtained for the least expensive unit indicates that the installed costs can be approximated as:

$25,903 + $1,811 (A)

(where A is the surface area of the unit in square metres).

EPA Form 2360-4 (4-80)
(PREVIOUSLY CIN. EPA FORM 267)
TYPING GUIDE SHEET

In general, the capital cost of dissolved air flotation units is relatively low, ranging from $30,000 for a unit of area 4.6 sq.m (50 sq. ft.) and the capacity to treat 225-450 L/min (60-180 gpm), to $70,000 for a unit of surface area 28 sq.m (300 sq. ft.) which could treat 1350-2700 L/min. (360-720 gpm), depending on the design criteria. Based on a detailed study on application of dissolved air flotation for clarification,* it was calculated that an installed dissolved air flotation unit which could treat 750 cu.m. of wastewater over a 24-hour period, would cost only $33,000. This is lower than the cost of providing one days equalization capacity for the same flow, which was estimated at $47,000. However, dissolved air flotation cannot provide the many advantages of equalization. For this reason, dissolved air flotation should not be considered as a replacement for equalization, but could be used to enhance some of the effects of equalization if space for extended equalization is severely limited. If possible, at least one days equalization capacity should be provided ahead of the dissolved air flotation unit.

If it is assumed that dissolved air flotation requires little or no labour input, that the addition of coagulants is not necessary for effective flotation because of the nature of the wastewater and that the scum and sludge from the operation can be disposed of on site at no charge, then the operating costs of a dissolved air flotation unit consist of (a) power costs and (b) maintenance costs, which manufacturers estimate at 1% of capital cost annually. These costs are presented as a function of the capacity of a unit in Figure 3 and can be approximated by the linear regression equation.

Annual cost of power and maintenance = $468 + $2(C) (where C is the capacity of the unit in litres per minute).

---

* Henry, J.G., and Gehr, R., Dissolved Air Flotation for Primary and Secondary Clarification. Canada Mortgage and Housing Corporation. Report SCAT-9. 1981.

EPA Form 2360-4 (4-80)
(PREVIOUSLY CIN EPA FORM 261)
TYPING GUIDE SHEET

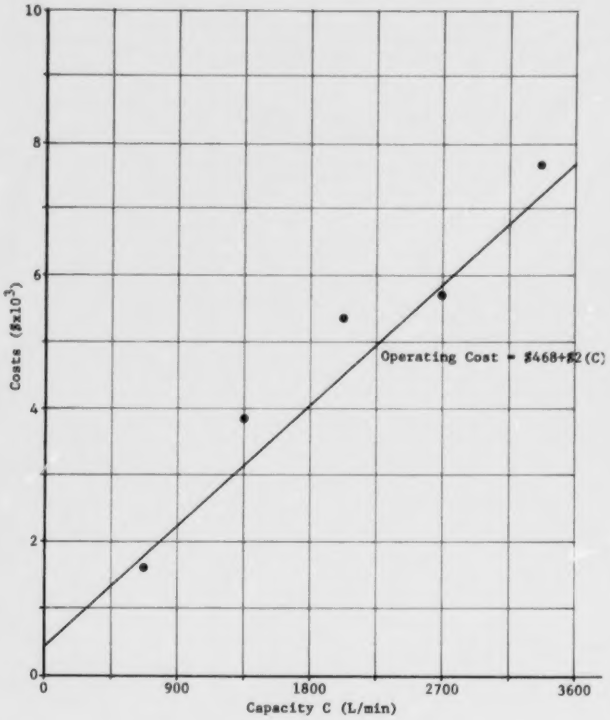


Figure 3 - Operating Costs of a Dissolved Air Flotation Unit as a Function of Design Capacity

AMMONIA STRIPPING

The basic technologies used for ammonia removal from coke-plant effluents are steam stripping and ion exchange. The first approach is broadly applied, but the second one is still at the development stage. Coke-plant effluents contain free and combined ammonia. The free ammonia may be stripped out by the application of steam, but to strip combined ammonia alkalization of the wastewater by the addition of caustic soda or lime is required.

The design of stills is based on: (a) the hydraulic flow to the still, which determines the surface area of the unit, and (b) the degree of ammonia removal required, which determines the number of plates or trays in the still, and hence its overall height. The quantity of steam used is a function of the influent temperature and the degree of ammonia removal required. The quantity of steam required for a given percentage of ammonia removal will decrease as the height of the still is increased.

EPA Form 2350-4 (4-80)
(PREVIOUSLY CIN. EPA FORM 287)
TYPING GUIDE SHEET

Because steam consumption accounts for a large portion of the operating costs of ammonia stills, careful design balances the height of the still and the steam requirements to achieve a least cost solution. The cost of steam can vary from one location to another and, because of the high capital costs of ammonia stills, construction of a high still to reduce steam consumption is not always warranted.

There are many variations of the basic technology of steam ammonia stripping. Some of these are: (a) free leg only, (b) conventional free-and-fixed leg still, with application of lime or caustic, (c) the Bethlehem Steel pre-liming system and its modification. Detailed discussion of the characteristics of each of these variations can be found elsewhere.

The data collected on capital costs of ammonia stills are presented as a function of the still design flow rate on Figure 4. There is a wide variation in the costs quoted from different sources. Plants 1, 2 and 3 all operate at a wastewater flow of 163 cu. m/d, but the cost of the stills vary by almost 100%. There are numerous reasons why this can occur. The total installed costs of a still will include for lime handling equipment in some cases, and not in others, where lime handling equipment was already available on site. Also, construction costs will vary from one location to another, and will depend to a certain extent on economic conditions at the time of construction. If the location of the ammonia still is remote from manufacturing centres, then this will be reflected in a higher installation cost. Piping lengths, instrumentation and pump requirements will vary from one installation to another, causing a variation in price. Also, the operating flow of a still may differ from its design flow rate, which would give a higher than expected cost.

It appears that the material for the still structure does not account for a major portion of the total capital cost. The data labelled 7, 8, 9, 10 and 11 on Figure 5 were obtained from an ammonia still manufacturer and are the manufacturer's estimates of the material cost for the still structure, including the internal trays and the dephlegmator, but do not account for the costs of labour, or any pumps, piping, chemical handling equipment or instrumentation. In some cases, this can account for a significant portion of the total capital cost of a still installation, particularly if extensive piping, (which is very labour intensive) is involved. Plant 8, which has an estimated cost of $750,000 for the construction material for the still structure only, has the same capacity as Plant 5, for which a total capital cost of $6M was quoted. In this case, the material used in the still structure accounted for 12.5% of the total capital cost of the installation.

EPA Form 2350-4 (4-80)
(PREVIOUSLY CIN. EPA FORM 237)

TYPING GUIDE SHEET

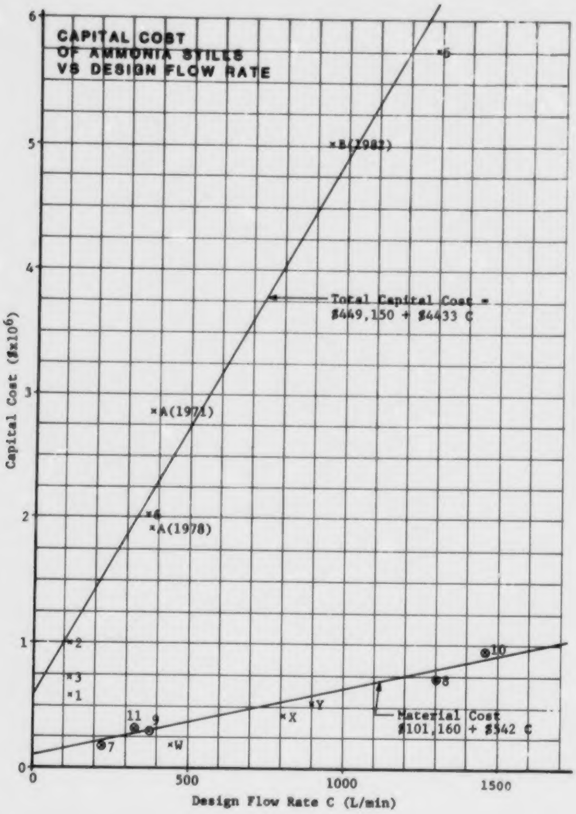


Figure 4 - Capital Cost of Ammonia Stills as a Function of Design Flow Rate

The total cost of installation of the ammonia still at Plant A in 1971 was $1,000,000. The designer of the still quoted the cost of materials for the still structure itself, including the internals and the dephlegmetor as $80,000. The balance of the cost included engineering fees, labour and the cost of installation of the lime handling system, and all other equipment, pumps, controls and piping related to operation of the still. In this case, the material cost of the still structure accounted for only 8% of the total capital cost quoted for the installation. The data labelled W, X and Y give lower costs for a complete ammonia stripping installation that the cost which were provided by a manufacturer for construction materials for the still structure and the dephlegmator only, hence these costs are discounted from this analysis.

A linear regression was carried out on the available data which indicated that the cost of materials for the still structure itself can be approximated by the equation:

Material Cost = $101,160 + $542 (C)

(where C is the design flow in litres per minutes).

In general, Plants A, B, 1, 2, 3, 5 and 6 give similar results for capital costs of ammonia stills as a function of design flow. A linear regression of these data, indicates that capital cost of ammonia stills can be approximated by the following formula:

Capital Cost \$ = \$449,150 + \$4,433 (C)

(where C is the design flow rate to the still, in litres per minute).

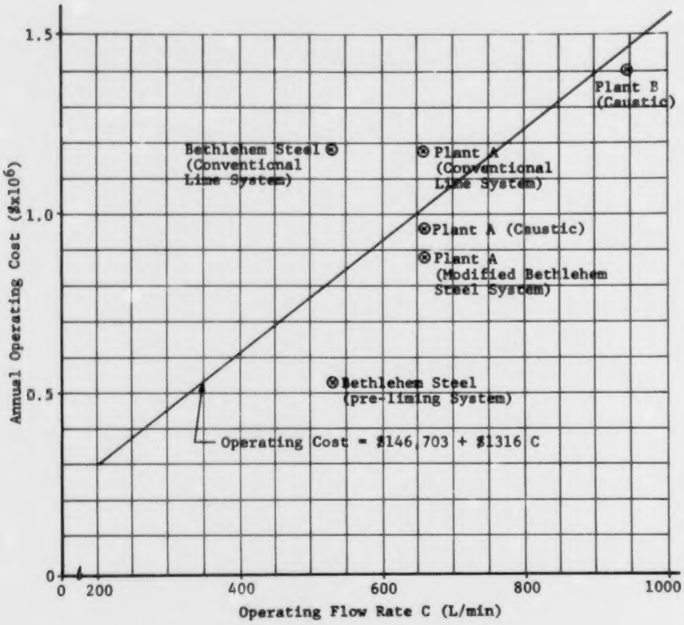


Figure 5 - Operating Costs of Ammonia Stills as a Function of Design Flow Rate

However, as each capital cost quotation used for this study included different items of equipment this formula should be used with caution.

Figure 5 presents the annual operating costs of ammonia stills as a function of wastewater flow rate. Plant A currently operates a modified Bethlehem Steel design, where effluent from the free leg of the still is limed, and settled in an inclined plate clarifier prior to entering the fixed leg of the still. In this manner, many of the operating problems associated with lime deposits on the trays of the fixed leg of the still have been reduced or eliminated. Operating costs are shown for the period when a conventional lime system was used at the plant, and also for a trial period when caustic was used for alkaline pH adjustment.

EPA Form 2350-4 (4-80)
(PREVIOUSLY CIN. EPA FORM 2...)
TYPING GUIDE SHEET

Other costs presented in Figure 5 include those quoted in a Bethlehem Steel study*, and those of a plant running a caustic system. The Bethlehem Steel System consists of overliming the still feed, which is settled in a clarifier prior to introduction to the fixed leg of the still. In this design, the free leg of the still is no longer necessary thus it results in a capital cost saving. All costs have been converted to December 1981 Canadian dollars for comparative purposes.

The costs of both the Plant A and Plant B caustic systems are approximately $2.80 per cu.m of wastewater treated and that of the current Plant A system, are slightly less, at $2.52 per cu.m. The costs for the conventional lime system at Plant A were developed based on information received from the plant operator, and include the increase in clean-out costs associated with using a conventional lime system at this plant, but do not take possible increases in steam requirements into account. The cost of treatment with a conventional lime system is estimated at $3.88/cu.m of wastewater treated. When Bethlehem Steel introduced the pre-liming system, they quoted the cost of conventional lime treatment at $2.92 US/cu.m and the cost of the pre-liming system as $1.68 US/cu.m. Converting these figures to December 1981 Canadian dollars gives high costs for both systems. However, a rate of inflation of 1% per month has been assumed during the period June 1977 to December 1981, which may be unreasonably high, as the costs associated with lime treatment may not have risen by 54% for that period. The result of converstion to December 1981 Canadian dollars is that the Bethlehem Steel figures for both a conventional lime system and a pre-liming system are considerably higher than the Plant A figures for similar treatment systems. The differences in cost can be partially explained by the fact that some of the steam used in Plant A is free, whereas Bethlehem Steel charged for all steam in its study. Also, the Bethlehem Steel conventional lime system used a steam rate of 240-360 g/L of wastewater treated, whereas the Plant A conventional lime system cost was based on a usage of 200 g/L of wastewater. No information was available on steam usage at Plant A prior to the installation of the clarifier ahead of the fixed leg. It is possible that steam usage was higher with a conventional lime system, however, this was not taken into account in the estimated treatment cost which asssumed current steam usage rates. The major cost of the conventional lime system in the Bethlehem Steel report is the cost of steam, which accounts for 80% of the total operating costs.

The clean-out costs cited by Bethlehem Steel for the conventional lime system are much lower than those incurred by Plant A, when it used for a conventional lime system, and are slightly lower than Plant A current clean-out costs after a conversion to the modified Bethlehem system, however,

---

* Rudzki, E.M., et al., An Improved Process for the Removal of Ammonia from Coke Plant Weak Ammonia Liquor. Iron and Steelmake, June 1977.

EPA Form 2360-4 (4-80)
(PREVIOUSLY CIN. EPA FORM 247)
TYPING GUIDE SHEET

BEGIN FIRST LINE OF TEXT HERE
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD: BEGIN SECTIONS HERE

these costs are a small percentage of total operational costs. The information in the Bethlehem paper did not include for the cost of operators for the plant, or for the extra costs of disposing of the increased quantity of lime sludge generated by the system which uses more lime than a conventional system, hence the operating costs quoted in their paper do not take into account some of the items covered in the Plant A cost breakdown.

The major advantage of the Bethlehem Steel system is the saving in steam costs, as the study found that steam consumption was reduced by 55% by the design changes described previously. The Bethlehem paper states that a steam rate of 130 g/L is adequate for their modified system, whereas Plant A, which operates a similar system, has found that a steam rate of 200 g/L is required to achieve an effluent containing less than 100 mg/L of ammonia. The difference in the designs of the fixed leg of both units may account for the lower steam requirements.

It should be stressed that the costs of both chemicals and steam will vary from one plant to another, so that it is sometimes difficult to compare quoted operating costs directly.

CONCLUSIONS

(1) A certain level of equalization of coke plant effluents is absolutely necessary, and can be considered either before and/or after ammonia stripping. It is most effective before both ammonia stripping and biological oxidation, as it would provide an influent of reasonably constant quality to both of these units. In this work, the advantages of extended equalization/retention periods have been discussed but not quantified. If space is not readily available at a site, the cost of large equalization/retention periods in terms of land usage may not be justified. In general, the capital cost of equalization/retention is relatively high.

(2) Dissolved air flotation is a compact system with reasonable capital and operating costs, which can be used effectively with or without addition of chemicals to remove oil, tar and a portion of the COD from coke plant effluents. This method of pretreatment would improve the performance of both the ammonia still and the biological system, but would not be justified after reasonably long equalization periods. It is most appropriate at plants where space is severely limited, and it can act as a supplement to equalization basins with low detention periods.

(3) At a daily wastewater flow of 750 cu.m the cost of dissolved air flotation is equivalent to the cost of 1.5 days equalization capacity, excluding land costs. At higher wastewater flows, the cost of dissolved air flotation is less significant in terms of equalization capacity. Therefore, the decision to consider dissolved air flotation will vary with the size of plant in question.

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA: OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

EPA Form 2350-4 (4-80)
(PREVIOUSLY CIN. EPA FORM 237)
TYPING GUIDE SHEET

(4) At present, there does not appear to be a technological substitute for steam ammonia stripping, which is the most feasible method for removing large quantities of ammonia from wastewater. This method has high capital and operating costs. Steam costs are the greatest component of the operating costs of an ammonia still, therefore research should be directed at optimizing still design to minimize steam usage.

(5) The operating costs of modified lime ammonia stills are much lower than those of conventional lime systems and appear to be slightly lower than those of a caustic system. For this reason, if a conventional lime system is in place at a plant, it is advisable to install a clarifier to reduce the solids loading on the fixed leg of the still and thus greatly reduce the numberof cleanout operations required. The investment required to modify the conventional lime system would soon be repaid by the savings in operating costs. However, at slightly higher operating costs, a caustic still may prove to be a more reliable and efficient system than a modified lime still.

EPA Form 2350-4 (4-80)
(PREVIOUSLY C1N. EPA FORM 237)

TYPING GUIDE SHEET

The work described in this paper was not funded by the U.S. Environmental Protection Agency. The contents do not necessarily reflect the views of the Agency and no official endorsement should be inferred.

TREATMENT OF COKE PLANT WASTEWATER WITH OR WITHOUT BLAST FURNACE BLOWDOWN WATER IN A TWO-STAGE BIOLOGICAL FLUIDIZED BED SYSTEM

by

S.G. Nutt, Senior Project Manager, Canviro Consultants Ltd.,
178 Louisa Street, Kitchener, Ontario, Canada, N2H 5M5

H. Melcer, Head, Biological Processes Section, Wastewater
Technology Centre, Environment Canada, P.O. Box 5050,
Burlington, Ontario, Canada, L7R 4A6.

I.J. Marvan, Manager, Dearborn Environmental Consulting Services
P.O. Box 3060, Station A, Mississauga, Ontario, Canada, L5A 3T5

P.M. Sutton, Senior Process Engineer, Dorr-Oliver Inc.,
77 Havemeyer Lane, Stamford, Conn. 06904

ABSTRACT

Pilot-scale treatability studies conducted at Environment Canada's Wastewater Technology Centre have demonstrated that the two-stage biological fluidized bed is an effective high-rate system for treatment of coke plant wastewater alone and in combination with blast furnace blowdown water. Greater than 90 percent removal of total nitrogen from undiluted coke plant wastewater was achieved at a total system HRT of 16 hours. A similar degree of treatment of a combined wastewater containing coke plant wastewater and blast furnace blowdown water was achieved at a total system HRT of 4.5 hours. In both cases, removal of conventional contaminants including FOC, phenolic compounds and CNS approached or exceeded 90 percent consistently.

Capital costs associated with treatment of 4950 $m^3 \cdot d^{-1}$ (1.31 MUSGPD) of combined wastewater were essentially identical to capital costs associated with treatment of 1300 $m^3 \cdot d^{-1}$ (0.34 MUSGPD) of coke plant wastewater. Although annual direct operating costs for treatment of the combined wastewater exceeded those related to coke plant wastewater treatment by approximately \$100,000, on a unit cost basis (\$ per m^3 treated) operating costs for treatment of the combined wastewater were less than half those estimated for treatment of coke plant wastewater alone.

INTRODUCTION

Byproduct coking operations and blast furnace operations are major sources of wastewater in an integrated steel mill. Effluents from byproduct coke ovens contain high concentrations of ammonia, thiocyanate, phenolic compounds, cyanide and a variety of complex hydrocarbons. Blowdowns from blast furnace gas cleaning recycle systems contain lesser, albeit significant, levels of ammonia and cyanide, but are relatively small contributors of organic contaminants.

Biological treatment processes are commonly applied to coke oven wastewaters to oxidize phenolic compounds and conventional organic contaminants. Recent research has shown that biological nitrification of coke plant wastewaters can be achieved under conditions of stringent SRT control (1,2,3). Treatment of blast furnace gas cleaning wastewater, beyond that necessary to effect suspended solids removal and to control scaling and corrosion in the gas scrubber system, has typically involved the application of physical-chemical methods to oxidize ammonia and cyanide. The most commonly applied process is alkaline breakpoint chlorination (4). Biological treatment methods are seldom applied to blast furnace blowdown streams due to the low concentrations of organic contaminants and the possible inhibitory effect of heavy metals present in the blowdown stream.

Several researchers have discussed the possibility of biologically treating a combined stream of coke plant wastewater and blast furnace blowdown water (4). This treatment approach may eliminate the use of freshwater dilution commonly practised by steel mills during treatment of coke plant wastewater. Furthermore, the utilization of a single treatment facility for the combined wastewater stream may provide significant economic advantage. The technical feasibility of combined treatment of coke plant wastewater and blast furnace blowdown water was recently demonstrated at laboratory-scale (5).

Pilot-scale treatability studies conducted at Environment Canada's Wastewater Technology Centre in Burlington, Ontario over the past two years have demonstrated that the biological fluidized bed process, operated in the pre-denitrification-nitrification flow mode, is an effective high-rate system for treatment of coke plant wastewater alone and in combination with blast furnace blowdown. The fluidized bed system was shown to offer significant advantages in terms of reduced reactor volumes due to the high biomass concentrations maintained on the fluidized support media. The pre-denitrification-nitrification flow mode was shown to reduce the oxygen requirements of the biological processes due to the anoxic removal of a large fraction of the wastewater organics as well as to minimize the process requirements for supplemental carbon and alkalinity.

Detailed results of the coupled fluidized bed biological treatment of coke plant wastewater alone (6,7,8) and in combination with blast furnace blowdown (9,10) have been presented elsewhere. In this paper, these performance data are briefly reviewed and process design and cost data are presented for coupled biological fluidized bed systems designed to treat coke plant wastewater with and without blast furnace blowdown water.

EPA Form 2350-4 (4-80)
(PREVIOUSLY CIN. EPA FORM 337)
TYPING GUIDE SHEET

EXPERIMENTAL PROGRAM

PILOT PLANT DESCRIPTION

The process flowsheet of the coupled fluidized bed pilot plant is shown in Figure 1. The plant configuration used for treatment of coke plant wastewater alone and in combination with blast furnace blowdown water was essentially the same with the exception that the facilities for supplemental methanol addition to the feed were not required during treatment of coke plant wastewater alone. The system was designed to operate as a two-stage separate sludge pre-denitrification-nitrification system to effect phenol oxidation, thiocyanate oxidation, cyanide removal and complete nitrogen control in separate anoxic and oxygenic biological reactors.

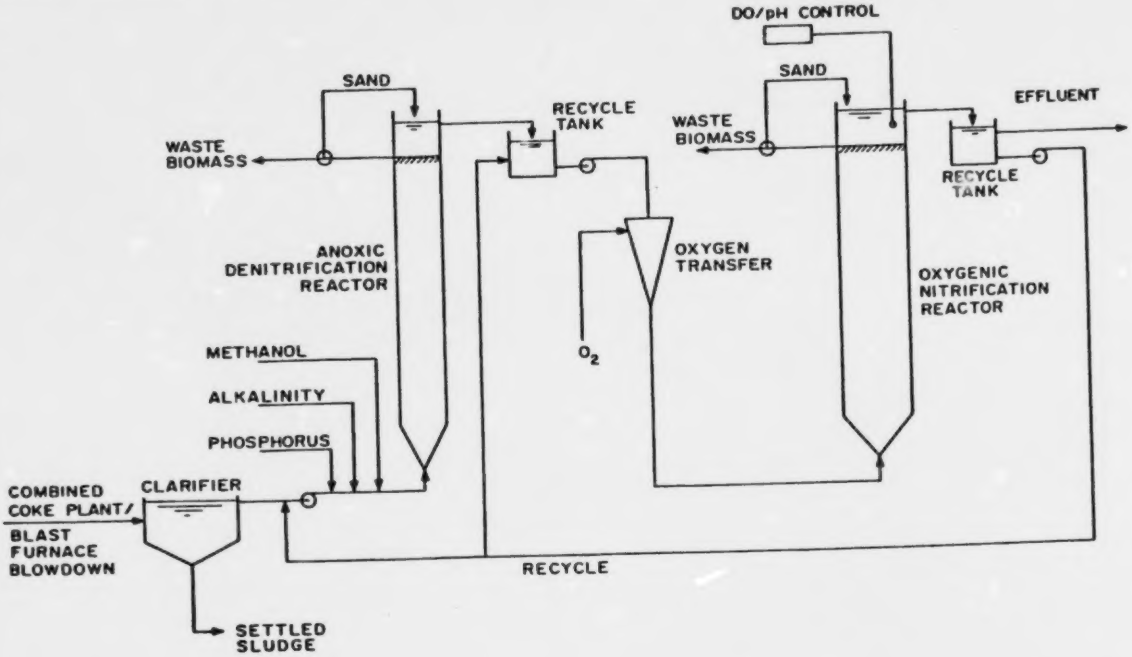

DO/pH CONTROL
SAND
SAND
EFFLUENT
RECYCLE TANK
WASTE BIOMASS
WASTE BIOMASS
RECYCLE TANK
ANOXIC DENITRIFICATION REACTOR
OXYGEN TRANSFER
OXYGENIC NITRIFICATION REACTOR
O_2
METHANOL
ALKALINITY
PHOSPHORUS
COMBINED COKE PLANT/ BLAST FURNACE BLOWDOWN
CLARIFIER
RECYCLE
SETTLED SLUDGE

FIGURE 1. PROCESS FLOWSHEET OF TWO-STAGE FLUIDIZED BED BIOLOGICAL TREATMENT SYSTEM

The anoxic denitrification reactor was cylindrical, 150 mm in diameter and 4.3 m in height. Fluidized bed height was controlled at approximately 2.2 m, equivalent to an empty bed reactor volume of approximately 31 litres, although some variation in reactor height was allowed, depending on operating conditions. The reactor had a conical inlet design to improve influent flow distribution.

The oxygenic nitrification reactor was also cylindrical, 290 mm in diameter and 4.3 m in height. Fluidized bed height was controlled at approximately 3.9 m, equivalent to an empty bed reactor volume of approximately 210 litres.

EPA Form 2350-4 (4-80)
(PREVIOUSLY CIN. EPA FORM 287)
TYPING GUIDE SHEET

The nitrification reactor had a downflow inlet design to reduce turbulence and shear in the reactor. Pure oxygen was supplied to the reactor through a downflow oxygen contactor provided by Dorr-Oliver Inc. Oxygen supply was automatically controlled by an analog PID feedback controller in response to effluent dissolved oxygen concentration.

Tankage and pumps were provided to recycle treated effluent to the anoxic reactor and the oxygenic reactor as required to maintain fluidization of the reactors, to return nitrified effluent for denitrification and ensure adequate oxygen transfer for the biological processes. A primary clarifier was included in the process flow sheet but was not found to be necessary for efficient pilot plant operation.

The pilot plant included feed systems to supply phosphoric acid as a biological nutrient, sodium bicarbonate for pH control and as a source of supplemental alkalinity for the nitrification reactions, and, in the case of treatment of the combined wastewater, methanol as a supplemental carbon source for the denitrification reactions. Temperature control was provided to maintain the reactors in the range from 25°C to 30°C.

The support media in both reactors was quartzite sand with an effective size ($^{d}10$) of 0.48 mm and a uniformity coefficient ($^{d}60/^{d}10$) of 1.23.

SOURCES OF PILOT PLANT FEED

Coke plant wastewater was obtained from the byproduct coke plant at Dofasco Inc. in Hamilton, Ontario. The wastewater consisted of ammonia still effluent obtained from the settling sump of a free and fixed-leg still treating excess flushing liquor from the coke oven operation plus a small flow of fractionator bottoms from the Phosam plant.

Blast furnace blowdown was obtained from a second integrated steel mill which included four blast furnaces served by two separate water recirculation systems. Recirculation system A, serving three of the four furnaces, was operated initially at a blowdown of approximately 50 percent but, during the course of the pilot plant study, blowdown was reduced to approximately 15 percent. Recirculation system B, serving the remaining blast furnace, operated at a blowdown of approximately 15 to 20 percent throughout the study. Sinter plant gas scrubber water discharged to recirculation system A.

EXPERIMENTAL PROCEDURES

The sampling schedules and analytical procedures followed during the pilot plant treatment of coke plant wastewater with and without blast furnace blowdown were similar and have been described in detail elsewhere (6,8,10).

The fluidized bed pilot plant was operated on coke plant wastewater alone for a period of approximately 18 months between July 1980 and December 1981. The experimental program consisted of an extended start-up and acclimation period followed by approximately 12 months of non-steady state operation. Process operating conditions during the non-steady state

EPA Form 2350-4 (4-80)
(PREVIOUSLY CIN. EPA FORM 287)

TYPING GUIDE SHEET

period were based on the results of the pseudo - steady state studies. Process design data were developed based on 48 consecutive days of non-steady state operation during which five batches of coke plant wastewater were treated in the fluidized bed pilot plant. The results of the non-steady state operating period are reviewed in this paper. Previous papers have presented the results of the start-up and pseudo-steady state operating periods (6,7).

Subsequent to the completion of the coke plant wastewater treatability studies, the fluidized bed pilot plant was operated for a period of approximately 6 months from January 1982 to July 1982 on a combined wastewater containing coke plant wastewater and blast furnace blowdown water. Ratios of blast furnace flowdown water to coke plant wastewater of 2 to 1 and 3 to 1 (by volume) were used to cover the range of conditions anticipated at full-scale. A ratio of 2:1 was used during the first four months and a ratio of 3:1 was used during the final two months of plant operation. Blowdown water from recirculation system B was used in the first mixed batch of feed covering the first 3 1/2 months of plant operation as system B contained a significantly higher nitrogen concentration than system A. All subsequent feed batches utilized blowdown water from recirculation system A. During the investigation, the process loading on the biological reactors was progressively increased to determine the minimum reactor hydraulic retention times required to maintain nitrification of the combined wastewater and to achieve a treated effluent quality comparable to that attained during treatment of coke plant wastewater. Due to the short-term nature of the experimental program, biological steady state conditions in terms of SRT were not attained in the process after step changes in the hydraulic loading.

RESULTS

COKE PLANT WASTEWATER TREATMENT

The mean process operating conditions for the anoxic and oxygenic reactors comprising the fluidized bed pilot plant during the non-steady state operating period are summarized in Table 1. The average system hydraulic retention time (HRT) was 17.7 hours. The HRT in the anoxic denitrification reactor was 2.4 hours. The HRT in the oxygenic nitrification reactor was 15.3 hours. Mean system SRT was 42.0 days.

The process performance, based on 48 consecutive days of plant operation, is summarized in Table 2. As evident from these performance data, removal of conventional carbonaceous contaminants (FOC) was consistently high. Phenolic compounds were removed to a median level of 0.16 $mg \cdot L^{-1}$, equivalent to a removal efficiency in excess of 99.9 percent.

As indicated by the data presented in Figure 2, efficient nitrification was consistently maintained despite a two-fold variation in the oxidizable nitrogen loading on the process. Median effluent NH_3-N concentration was 1.3 $mg \cdot L^{-1}$, equivalent to a removal efficiency exceeding 99 percent. The total cyanide content of the coke plant wastewater was reduced

EPA Form 2350-4 (4-80)
(PREVIOUSLY CIN. EPA FORM 237)
TYPING GUIDE SHEET

to 6.1 $mg \cdot L^{-1}$ from a median value of 8.0 mg $TCN.L^{-1}$. Based on a limited amount of data collected at the end of the pilot plant study, the concentration of cyanide compounds amenable to chlorination in the treated effluent was reduced to the detection limit (0.01 $mg \cdot L^{-1}$).

TABLE 1: MEAN PROCESS OPERATING CONDITIONS DURING TREATMENT OF COKE PLANT WASTEWATER

PARAMETER	DENITRIFICATION REACTOR	NITRIFICATION REACTOR	SYSTEM
HRT (hours)	2.4	15.3	17.7
SRT (days)	13.3	62.4	42.0
Reactor VS ($g \cdot L^{-1}$)	16.3	14.5	-
Recycle Ratio	47.5	270.0	-
Effluent D.O. ($mg \cdot L^{-1}$)	-	2.9 - 3.7	-
Temp. (°C)	25.2 - 28.0	25.5 - 28.0	-
Ammonia Loading* ($gNH_3\text{-}N \cdot g\ VS^{-1} \cdot d^{-1}$)	-	0.021	-

* Includes contribution of CNS to oxidizable nitrogen concentration.

TABLE 2: PROCESS PERFORMANCE DURING TREATMENT OF COKE PLANT WASTEWATER

PARAMETER	FEED*	EFFLUENT*	REMOVAL (%)
FOC	700 ± 51.	56.0 ± 4.	92.0
COD_F	2750 ± 297.	478.0 ± 90.	82.6
Phenolics	413 ± 33.	0.16 ± 0.03	>99.9
TKN_F	247 ± 41.	11.9 ± 1.6	95.2
NH_3-N	113 ± 57.	1.3 ± 0.6	99.4**
CNS	346 ± 61.	2.4 ± 0.5	99.4
TCN	8.0 ± 1.4	6.1 ± 1.4	23.8
NO_2-N	- -	3.0 ± 0.9	-
NO_3-N	- -	1.6 ± 0.8	-
TN	246 ± 41.	16.5 ± -	93.3
SS	- -	232 ± 76.0	-

* Concentration in $mg \cdot L^{-1}$ based on 48 consecutive days of operation.
** Includes contribution of CNS to oxidizable nitrogen concentration.

As shown in Figure 3, the oxidized nitrogen (NO_T-N) concentration in the denitrification reactor effluent was reduced to less than 1 $mg \cdot L^{-1}$ consistently without supplementary carbon addition. The raw feed FOC/TKN ratio averaged approximately 2.8 during the non-steady period, significantly lower than the ratio of 3.5 found by Bridle *et al* (1) to be required in suspended growth pre-denitrification systems treating coke plant wastewater.

BEGIN FIRST LINE OF TEXT HERE
TOP OF IMAGE AREA
DROPPED HEAD; BEGIN SECTIONS HERE

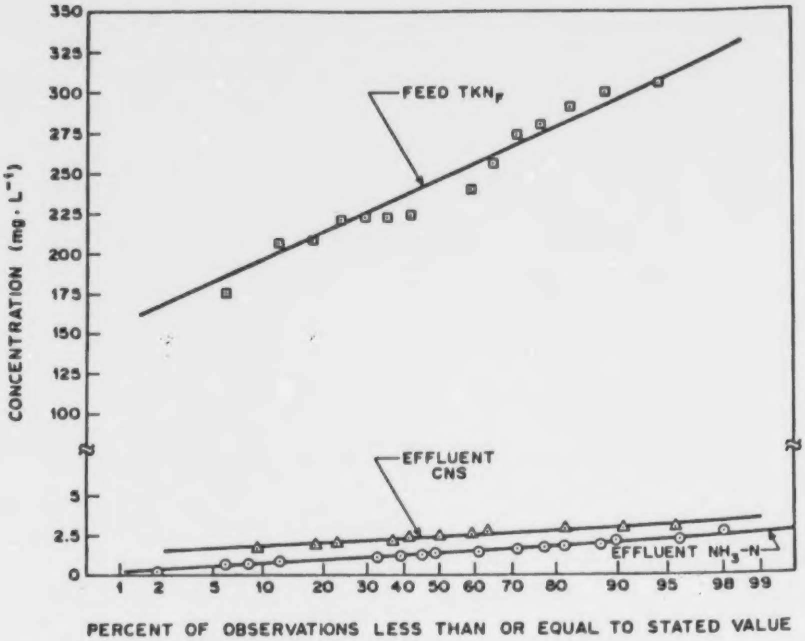


FIGURE 2. REMOVAL OF OXIDIZABLE NITROGEN AND THIOCYANATE FROM COKE PLANT WASTEWATER

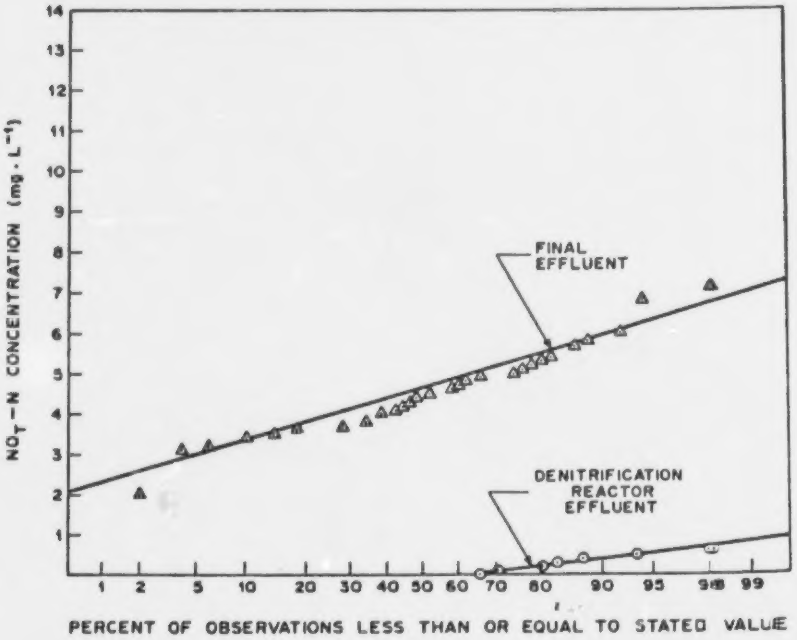


FIGURE 3. REMOVAL OF OXIDIZED NITROGEN FROM COKE PLANT WASTEWATER

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

EPA Form 2350-4 (4-80)
(PREVIOUSLY CIN, EPA FORM 227)
TYPING GUIDE SHEET

Total nitrogen removal efficiency over 48 consecutive days of non-steady state operation was approximately 93.3 percent.

COMBINED COKE PLANT WASTEWATER AND BLAST FURNACE BLOWDOWN TREATMENT

The characteristics of the individual components of the blended feed and the average concentrations of contaminants in the combined wastewater used as feed to the fluidized bed pilot plant during the six month investigation are shown in Table 3. The coke plant wastewater used in the combined feed was similar to that treated previously in terms of the concentration of nitrogen compounds and thiocyanate but contained lower concentrations of organic contaminants. The nitrogen content of the combined wastewater was more strongly affected by the characteristics of the coke plant wastewater than by the ratio of blast furnace blowdown to coke plant wastewater utilized.

TABLE 3: CHARACTERISTICS OF INDIVIDUAL WASTE COMPONENTS AND COMBINED WASTEWATER

PARAMETER ($mg \cdot L^{-1}$)	COKE PLANT WASTEWATER	BLAST FURNACE BLOWDOWN SYSTEM A	BLAST FURNACE BLOWDOWN SYSTEM B	COMBINED WASTEWATER
FOC	550.	11.	8.	215.
Phenolics	241.	5.1	0.1	119.
NH_3-N	183.	22.1	33.4	66.4
CNS	290.	3.3	1.7	98.1
TCN	5.0	5.3	1.6	1.8
CN_A*	2.4	5.2	1.5	0.5
TKN	307.	28.2	40.0	111.
Total Zinc	0.4	20.3	6.1	2.0

* Cyanide amenable to chlorination

The range of operating conditions applied during the six-month treatability study are summarized in Table 4. As discussed, the experimental program involved sequential changes in the process loading to determine the minimum reactor HRT's required to maintain efficient nitrification and denitrification in the system. Total system HRT ranged from a minumum of 4 hours to a maximum of approximately 20 hours.

The data presented in Table 5 indicate that removal of organic contaminants (measured as FOC and phenolic compounds), thiocyanate and cyanide was consistently high throughout the investigation despite step changes in process loading and variations in feed quality. The removal efficiency of phenolic compounds and thiocyanate exceeded 99 percent throughout the period of pilot plant operation. Removal of nitrogen compounds (NH_3-N, TKN and NO_T-N) depended on the process loading conditions as well as the feed characteristics.

BEGIN FIRST LINE OF TEXT HERE
CENTER OF PAGE
TOP OF IMAGE AREA

TABLE 4: RANGE OF PROCESS OPERATING CONDITIONS DURING TREATMENT OF COMBINED WASTEWATER

PARAMETER	DENITRIFICATION REACTOR	NITRIFICATION REACTOR
HRT (hours)	0.5 - 2.6	3.5 - 17.5
SRT (days)	13. - 47.	72. - 650.
Reactor VS ($g \cdot L^{-1}$)	8.9 - 26.8	14.9 - 26.2
Recycle Ratio	7 - 50	50 - 270
Effluent D.O. ($mg \cdot L^{-1}$)	-	1.8 - 5.6
Temp. (°C)	24 - 31	24 - 31
Ammonia Loading* ($g\ NH_3\text{-}N \cdot g\ VS^{-1} \cdot d^{-1}$)	-	0.005 - 0.037

* Includes contribution of CNS to oxidizable nitrogen concentration.

DROPPED HEAD, BEGIN SECTIONS HERE

TABLE 5: REMOVAL OF FOC, PHENOLIC COMPOUNDS, THIOCYANATE AND CYANIDE FROM COMBINED WASTEWATER

PARAMETER	FEED*	EFFLUENT*	REMOVAL (%)
FOC	215. ± 66.	23. ± 6.	89.3
Phenolic Compounds	119. ± 36.	0.09 ± 0.04	>99.9
CNS	98.1 ± 32.	0.7 ± 0.5	99.3
TCN	1.8 ± 1.3	0.8 ± 0.9	57.9
CN_A	0.5 ± 0.8	0.1 ± 0.3	77.8

* Concentration in $mg \cdot L^{-1}$ based on 196 consecutive days of operation.

Maximum specific denitrification rates for the combined wastewater were not significantly different than the rates attained during treatment of coke plant wastewater alone, averaging approximately 0.15 g $NO_T\text{-}N \cdot g\ VS^{-1} \cdot d^{-1}$. Complete denitrification of the combined wastewater was attained at significantly lower FOC/TKN ratios than those required for similar treatment of coke plant wastewater alone. Mass balances around the denitrification reactor indicated the anoxic removal of between 0.84 and 1.26 mg FOC per mg $NO_T\text{-}N$ removed compared to the anoxic removal of 2.8 to 3.0 mg FOC per mg $NO_T\text{-}N$ during treatment of coke plant wastewater.

The most significant impact of variations in process loading on system performance was related to nitrification efficiency. As shown in Figure 4, operation at oxidizable nitrogen loadings of up to 0.031 g $NH_3\text{-}N \cdot g\ VS^{-1} \cdot d^{-1}$ resulted in treated effluent $NH_3\text{-}N$ concentrations consistently less than 2.0 $mg \cdot L^{-1}$. At higher loadings, instability in the efficiency of nitrification was evident as indicated by the variability in treated effluent $NH_3\text{-}N$ concentrations at these loading conditions.

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

EPA Form 2350-4 (4-80)
(PREVIOUSLY CIN. EPA FORM 287)
TYPING GUIDE SHEET

BEGIN FIRST LINE OF TEXT HERE
CENTER OF
TOP OF IMAGE AREA
DROPPED HEAD; BEGIN SECTIONS HERE

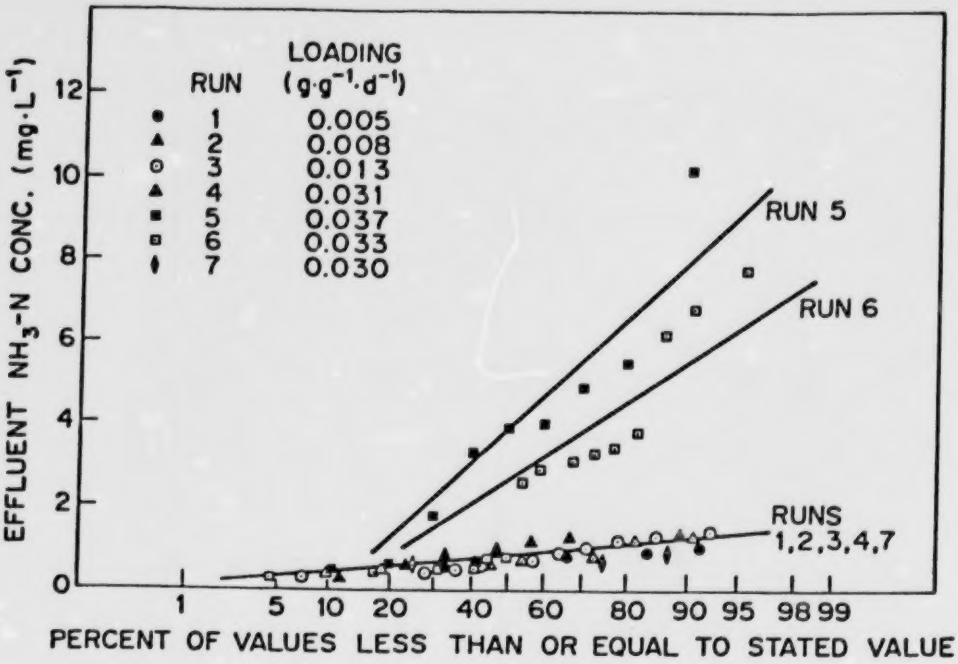


FIGURE 4. EFFLUENT NH_3-N CONCENTRATION DURING TREATMENT OF COMBINED WASTEWATER

Figure 5 indicates the effect of process loading on effluent quality in terms of NH_3-N concentration. At oxidizable nitrogen loadings up to 0.031 g NH_3-N·g $VS^{-1}·d^{-1}$, average effluent ammonia nitrogen concentrations of less than 1 mg·L^{-1} were attained. At higher loadings, a deterioration in effluent quality was evident as the loading exceeded the maximum specific nitrification rate of the system. For the purpose of comparison, stable nitrification of coke plant wastewater alone was achieved at nitrogen loadings up to approximately 0.022 g NH_3-N·g $VS^{-1}·d^{-1}$.

Nitrification efficiency was impaired during periods when supplemental carbon as methanol was unnecessarily added to the denitrification system. Zinc concentrations of up to approximately 3.4 mg·L^{-1} did not appear to affect nitrification in the fluidized bed system. At concentrations of 7 mg Zn·L^{-1}, there appeared to be some inhibition to the nitrification system but further data are necessary to confirm this observation. Preliminary results indicated that zinc could be precipitated from the combined wastewater by adjustment of pH to the range of 9 to 10.

The suspended solids content of the treated effluent from the fluidized bed system was significantly lower during treatment of the combined wastewater compared to that achieved during treatment of coke plant wastewater alone. The average effluent suspended solids concentration during treatment of the combined wastewater was approximately 20 mg·L^{-1} compared to an average level in excess of 200 mg·L^{-1} during treatment of coke plant wastewater (Table 2).

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS

EPA Form 2350-4 (4-80)
(PREVIOUSLY CIN. EPA FORM 287)
TYPING GUIDE SHEET

BEGIN FIRST LINE OF TEXT HERE
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD; BEGIN SECTIONS HERE

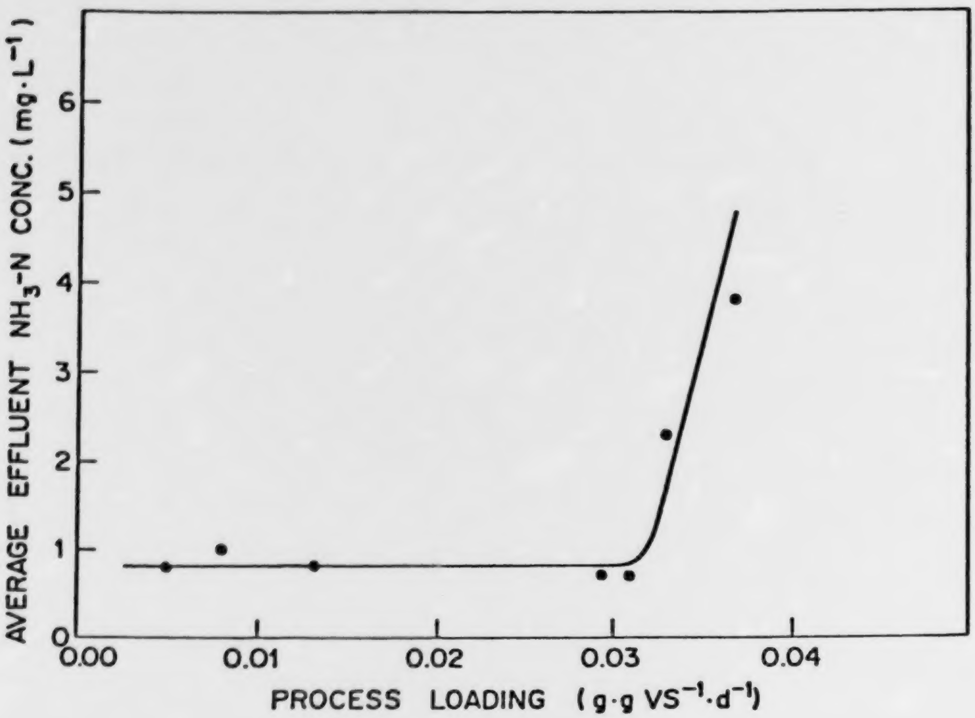


FIGURE 5. EFFECT OF PROCESS LOADING ON NITRIFICATION EFFICIENCY

PROCESS DESIGN AND COST ESTIMATES

DESIGN BASIS

Process design details for a coupled biological fluidized bed system to treat coke plant wastewater and a combined stream of coke plant wastewater and blast furnace blowdown water were developed based on the pilot-scale treatability studies. Design flows, wastewater characteristics and treated effluent quality for each case are summarized in Table 6. Raw wastewater qualities were based on the actual characteristics of coke plant wastewater and blast furnace blowdown measured during the pilot plant studies. Design flow of coke plant wastewater was 1300 $m^3 \cdot d^{-1}$ in both cases. Design flow of blast furace blowdown water was 3650 $m^3 \cdot d^{-1}$, equivalent to 2.8 times the flow of coke plant wastewater.

Process design details for the coke plant treatment system and the combined wastewater treatment system are compared in Table 7. The process design flowsheet for the coke plant wastewater treatment system is shown schematically in Figure 6. A comparative schematic for the treatment system designed for the combined wastewater is shown in Figure 7. As indicated in Table 7, the coke plant wastewater treatment system was designed to provide

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

PAGE NUMBER
EPA Form 2350-4 (4-83)
(PREVIOUSLY CIN. EPA / ORM 287)
TYPING GUIDE SHEET

a total system HRT of 16 hours compared to a system HRT of approximately 4.2 hours for equivalent treatment of the combined wastewater. A flocculator-clarifier was included in the coke plant wastewater treatment flowsheet to achieve the required effluent suspended solids concentration. Effluent suspended solids removal was not necessary during treatment of the combined wastewater.

TABLE 6: PROCESS DESIGN BASIS FOR FLUIDIZED BED SYSTEMS

PARAMETER	RAW WASTEWATERS			TREATED EFFLUENTS	
	COKE PLANT WASTEWATER	BLAST FURNACE BLOWDOWN	COMBINED WASTEWATER	COKE PLANT WASTEWATER	COMBINED WASTEWATER
Flow ($m^3 \cdot d^{-1}$)	1300.	3650.	4950.	1300.	4950.
FOC ($mg \cdot L^{-1}$)	700.	10.	190.	50.	20.
NH_3-N ($mg \cdot L^{-1}$)	100. ± 50.	30. ± 10.	48. ± 20.	1.	1.
CNS ($mg \cdot L^{-1}$)	300.	1.	80.	2.	1.
TKN ($mg \cdot L^{-1}$)	200.	40.	82.	-	-
NO_T-N ($mg \cdot L^{-1}$)	-	-	-	15.	15.
SS ($mg \cdot L^{-1}$)	-	-	-	30.	30.

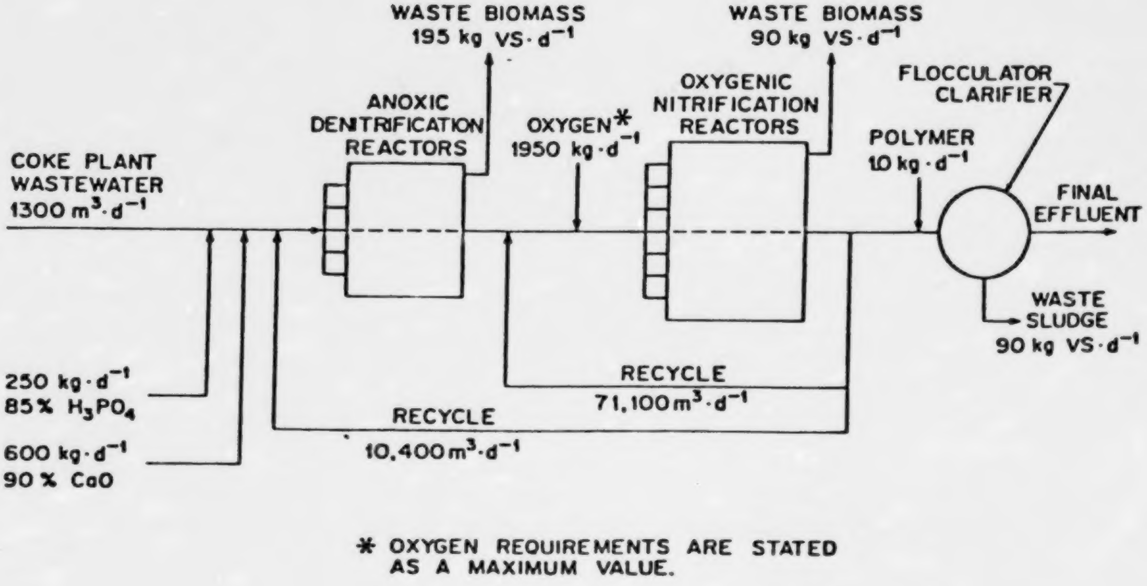

WASTE BIOMASS
195 kg VS·d⁻¹
WASTE BIOMASS
90 kg VS·d⁻¹
ANOXIC
DENITRIFICATION
REACTORS
OXYGEN*
1950 kg·d⁻¹
OXYGENIC
NITRIFICATION
REACTORS
FLOCCULATOR
CLARIFIER
POLYMER
1.0 kg·d⁻¹
COKE PLANT
WASTEWATER
1300 m³·d⁻¹
FINAL
EFFLUENT
WASTE
SLUDGE
90 kg VS·d⁻¹
RECYCLE
71,100 m³·d⁻¹
RECYCLE
10,400 m³·d⁻¹
250 kg·d⁻¹
85% H₃PO₄
600 kg·d⁻¹
90% CaO
* OXYGEN REQUIREMENTS ARE STATED AS A MAXIMUM VALUE.

FIGURE 6. PROCESS DESIGN FLOWSHEET FOR TREATMENT OF COKE PLANT WASTEWATER

TABLE 7. DESIGN SPECIFICATIONS FOR FLUIDIZED BED TREATMENT SYSTEMS

PARAMETER	COKE PLANT WASTEWATER SYSTEM		COMBINED WASTEWATER SYSTEM	
	DN REACTOR	NIT REACTOR	DN REACTOR	NIT REACTOR
HRT (hours)	2.0	14.0	0.53	3.7
Fluid Bed Ht. (m)	5.5	6.4	2.6	6.4
Reactor Ht. (m)	7.6	7.6	4.6	7.6
Reactor Area (m^2)	19.9	119.	42.2	119.
Hydraulic Flux ($m \cdot min^{-1}$)	0.40	0.48	0.40	0.48
Recycle Ratio	8.0	62.7	4.0	15.8
Sand Inventory (tonnes)	87.	609.	87.	609.

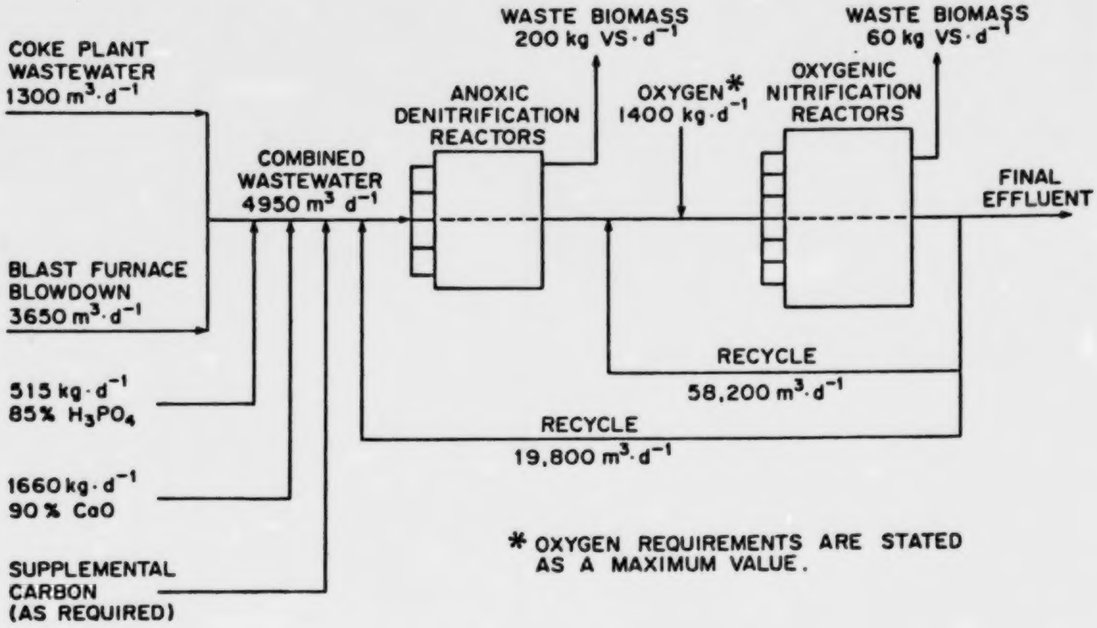

COKE PLANT WASTEWATER 1300 m³·d⁻¹
BLAST FURNACE BLOWDOWN 3650 m³·d⁻¹
515 kg·d⁻¹ 85% H₃PO₄
1660 kg·d⁻¹ 90% CaO
SUPPLEMENTAL CARBON (AS REQUIRED)
COMBINED WASTEWATER 4950 m³ d⁻¹
ANOXIC DENITRIFICATION REACTORS
WASTE BIOMASS 200 kg VS·d⁻¹
OXYGEN* 1400 kg·d⁻¹
OXYGENIC NITRIFICATION REACTORS
WASTE BIOMASS 60 kg VS·d⁻¹
FINAL EFFLUENT
RECYCLE 58,200 m³·d⁻¹
RECYCLE 19,800 m³·d⁻¹
* OXYGEN REQUIREMENTS ARE STATED AS A MAXIMUM VALUE.

FIGURE 7. PROCESS DESIGN FLOWSHEET FOR TREATMENT OF COMBINED COKE PLANT WASTEWATER/BLAST FURNACE BLOWDOWN

CAPITAL AND OPERATING COST ESTIMATES

On the basis of the process designs developed for the biological fluidized bed systems, preliminary cost estimates were developed for major capital items and for direct operating costs (chemicals and power) related to the treatment systems.

Capital cost estimates for the coupled fluidized bed system are summarized in Table 8. In both cases, it was assumed that pipeline oxygen would be available from the cryogenic generator associated with the BOF. It was also assumed that the lime requirements could be satisfied from the lime feeding system associated with the fixed-leg ammonia still and costs for a dedicated lime slaking facility and lime slurry feed system were not included in the cost estimate. Reactor costs were based on parallel anoxic and oxygenic fluidized beds.

TABLE 8: COMPARISON OF CAPITAL COSTS RELATED TO COKE PLANT TREATMENT WITH AND WITHOUT BLAST FURNACE BLOWDOWN

ITEM	COST (CANADIAN $ x 1000)	
	WITHOUT BLAST FURNACE BLOWDOWN	WITH BLAST FURNACE BLOWDOWN
1. Equipment, instrumentation and engineering for reactors and clarifier	1,010.	1,050.*
2. Concrete reactors, oxygenators, pump sumps and clarifier	460.	413.*
3. Pumps and pump rooms	292.	300.
4. Piping, valving (erected basis)	283.	276.
5. Installation of equipment, motor control center, wiring, site work	312.	300.
TOTAL	2,357.	2,339.

* No clarifier required for treatment of combined wastewater

As shown in Table 8, the capital costs associated with treatment of 1300 $m^3 \cdot d^{-1}$ of coke plant wastewater were essentially the same as those associated with treatment of 4950 $m^3 \cdot d^{-1}$ of combined coke plant wastewater and blast furnace blowdown.

Annual direct operating costs for chemicals and power for both treatment systems are summarized in Table 9. The chemical requirements for each system were shown in the process design flowsheets (Figures 6 and 7).

TABLE 9: COMPARISON OF ANNUAL DIRECT OPERATING COSTS RELATED TO COKE PLANT TREATMENT WITH AND WITHOUT BLAST FURNACE BLOWDOWN

ITEM	COST (CANADIAN $)	
	WITHOUT BLAST FURNACE BLOWDOWN	WITH BLAST FURNACE BLOWDOWN
1. Phosphoric Acid 85% H_3PO_4 @ $0.90 per kg	82,100.	169,300.
2. Lime - bulk quicklime (90% CaO) @ $0.061 per kg	13,400.	37,000.
3. Oxygen @ $0.06 per kg*	28,500.	21,900.
4. Polymer @ $6.30 per kg	2,300.	0.
5. Power @ $0.03 per kwh	24,600.	24,250.
TOTAL ANNUAL COST	150,900.	252,450.
UNIT COST ($ per m^3 treated)	0.32	0.14

* Based on pipeline oxygen from cryogenic generator supplying BOF.

Based on the design wastewater quality, supplemental carbon addition would not be necessary in either system to maintain complete denitrification. Operating costs for treatment of the combined wastewater were approximately \$100,000 per year higher than similar costs for treatment of coke plant wastewater. The cost difference is primarily the result of increased costs associated with higher phosphoric acid utilization. On a unit cost basis (\$ per m^3 treated), operating costs associated with treatment of the combined wastewater were less than half the costs associated with treatment of coke plant wastewater alone. In considering the cost implications of treating coke plant wastewater alone, the capital and operating costs associated with separate treatment of blast furnace blowdown by alkaline chlorination or other suitable process must be included in the evaluation of the overall wastewater management scheme for the specific installation.

CONCLUSIONS

Based on pilot-scale investigations of the coupled fluidized bed process for nitrification and denitrification of coke plant wastewater with and without blast furnace blowdown water, the following conclusions can be drawn:

- To achieve greater than 90 percent removal of total nitrogen from undiluted coke plant wastewater required a total system HRT of approximately 16 hours. A similar degree of treatment of combined wastewater containing coke plant wastewater and blast furnace blowdown water was achieved at a total system HRT of approximately 4.5 hours.
- In both cases, removal of conventional contaminants including FOC, phenolic compounds and CNS approached or exceeded 90 percent consistently. Effluent quality in terms of FOC, phenolic compounds, CNS, TCN and suspended solids was superior during treatment of the combined wastewater compared to that achieved during treatment of coke plant wastewater.
- Estimated capital costs associated with treatment of 4950 $m^3 \cdot d^{-1}$ of combined wastewater were essentially identical to capital costs associated with treatment of 1300 $m^3 \cdot d^{-1}$ of coke plant wastewater.
- Annual direct operating costs related to treatment of coke plant wastewater with blast furnace blowdown water were approximately \$100,000 per year higher than those estimated for treatment of coke plant wastewater alone. On a unit cost basis (\$ per m^3 treated), operating costs associated with treatment of the combined wastewater were less than half those associated with treatment of coke plant wastewater alone.

ACKNOWLEDGEMENTS

The authors wish to express their appreciation to Dofasco Inc. for their co-operation throughout the study and their financial support of the combined wastewater treatability investigation. In addition, the contributions of Mr. R.R. Evans of Dorr-Oliver Inc. to the development of the cost estimates is gratefully acknowledged.

EPA Form 2350-4 (4-80)
(PREVIOUSLY EIN. EPA FORM 287)
TYPING GUIDE SHEET

REFERENCES

1. Bridle, T.R., Bedford, W.K. and B.E. Jank, "Biological Nitrogen Control of Coke Plant Wastewaters", Prog. Wat. Tech., 12, (1980).

2. Medwith, B.W. and J.F. Lefelhocz, "Single-Stage Biological Treatment of Coke Plant Wastewaters with a Hybrid Suspended Growth - Fixed Film Reactor", Proc. of the 36th Purdue Industrial Waste Conf., 68, (1981).

3. Wong-Chong, G. and J.D. Hall, "Single-Stage Nitrification of Coke Plant Wastewater", Proc. of the Symposium on Iron and Steel Pollution Abatement Technology for 1980, EPA-600/9-81-017, 395, (1981).

4. Hofstein, H. and H.J. Kohlmann, "An Investigation of Foreign By-Product Coke Plant and Blast Furnace Wastewater Control Technology", Proc. of the Symposium on Iron and Steel Pollution Abatement Technology for 1980, EPA-600/9-81-017, (1981).

5. Gauthier, J.J., Jones, D.D., Wilson, L.W. and C.R. Majors, "Combined Biological Treatment of Coke Plant Wastewater and Blast-Furnace Recycle - Water System Blowdown", Proc. of the 36th Purdue Industrial Waste Conference, 77, (1981).

6. Nutt, S.G., Melcer, H. and J.H. Pries, "Two-Stage Biological Fluidized Bed Treatment of Coke Plant Wastewater for Nitrogen Control", presented at the 54th Water Pollution Control Federation Conference, Detroit, Michigan, (1981).

7. Nutt, S.G., Melcer, H., Marvan, I.J. and P.M. Sutton, "Treatment of Coke Plant Wastewater in the Coupled Pre-Denitrification Fluidized Bed Process", presented at the 37th Purdue Industrial Waste Conderence, Lafayette, Ind., (1982).

8. Nutt, S.G. and I.J. Marvan, "Biological Fluidized Bed Treatment of Complex Industrial Wastes for Nitrogen and Contaminant Control", Final Report to Environmental Protection Service, Environment Canada (In press).

9. Melcer, H., Nutt, S.G., Marvan, I.J. and P.M. Sutton, "Combined Treatment of Coke Plant Wastewater and Blast Furnace Blowdown Water in a Coupled Biological Fluidized Bed System", presented at the 55th Water Pollution Control Federation Conference, St. Louis, Missouri, (1982).

10. Nutt, S.G. and I.J. Marvan, "Biological Fluidized Bed Treatment of Combined Coke Plant Wastewater and Blast Furnace Blowdown", Final Report to Environmental Protection Service, Environment Canada, (In press).

The work described in this paper was not funded by the U.S. Environmental Protection Agency. The contents do not necessarily reflect the views of the Agency and no official endorsement should be inferred.

PHYSICAL/CHEMICAL TREATMENT OF COKE PLANT WASTEWATERS

by: James R. Zwikl
Nicholas S. Buchko
Shenango Incorporated
Pittsburgh, PA 15225

David R. Junkins
Roy F. Weston, Inc.
West Chester, PA 19380

ABSTRACT

A physical/chemical wastewater treatment facility consisting of activated carbon followed by alkaline chlorination was placed in operation at the coke plant of Shenango Incorporated in September 1979. This paper discusses the plant design characteristics, the operating experiences encountered with the activated carbon and alkaline chlorination portions of the plant and the effects of inflation and chemical availability on the operating costs of the facility. In addition, the current performance of the plant is compared with the recently promulgated Best Practicable Technology (BPT), Best Available Technology (BAT) and Best Conventional Technology (BCT) effluent limitation guidelines for cokemaking facilities. Finally, a brief discussion is presented on the ability of the system to remove priority pollutants.

BACKGROUND

Shenango Incorporated is a privately owned corporation headquartered in Pittsburgh, Pennsylvania. The Coke & Iron Division of Shenango is located on Neville Island, Pennsylvania, and is engaged in the production of iron, coke, and coke by-products.

The Coke & Iron Division consists of three major departments: Coke Plant, Blast Furnace, and Steam and Power. The Coke Plant presently consists of two operating coke batteries (35 ovens/battery), a new 56 oven battery presently being heated up and a by-products plant. The Blast Furnace department consists of two furnaces (1 operating and 1 stand-by), while the Steam and Power department consists of a boiler house which contains four boilers, and power generating facilities. (Figure 1 is a schematic of water distribution through the plant.)

In August 1971, in an effort to achieve compliance with the applicable state effluent limitations, Shenango commissioned The Chester Engineers to conduct a feasibility study on wastewater treatment. The results of the study indicated that treatment of a combination of coke plant waste streams constituting about 2.5 percent of the total plant wastewater of 24 mgd (90,840 m^3/d) would be required to meet the projected limitations for cyanide and phenol.

The streams which would require treatment all originated within the Coke Plant and included: waste ammonia liquor; excess final cooler wastewater; light oil separator wastes; hot oil decanter wastes; and ammonia liquor cooling tower blowdown in the event that cooler leakage should contaminate the blowdown (see Figure 2).

Additional studies were conducted by The Chester Engineers to determine the most cost-effective method of treatment. The treatment concepts investigated included biological and physical-chemical (ozonation, activated carbon, alkaline chlorination, etc.).

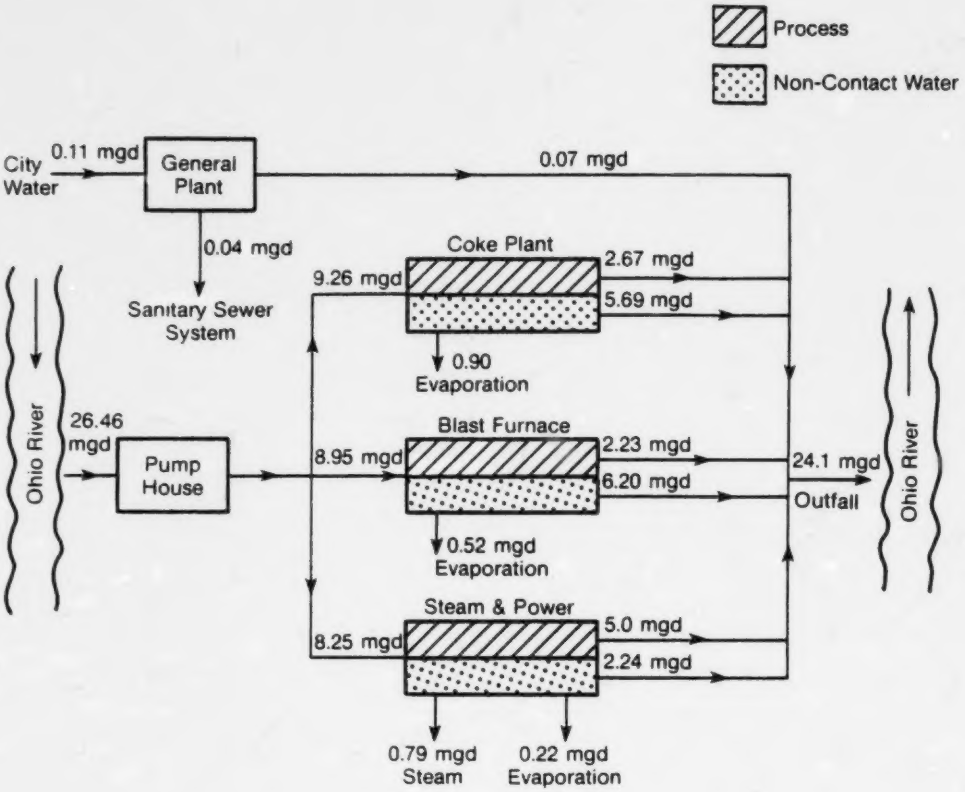

Process
Non-Contact Water
City Water
0.11 mgd
General Plant
0.07 mgd
0.04 mgd
Sanitary Sewer System
Coke Plant
9.26 mgd
2.67 mgd
5.69 mgd
0.90 Evaporation
Ohio River
26.46 mgd
Pump House
Blast Furnace
8.95 mgd
2.23 mgd
6.20 mgd
24.1 mgd
Outfall
Ohio River
0.52 mgd Evaporation
Steam & Power
8.25 mgd
5.0 mgd
2.24 mgd
0.79 mgd Steam
0.22 mgd Evaporation

Figure 1. Plant Water Flow Schematic
Shenango Incorporated
Pittsburgh, Pennsylvania

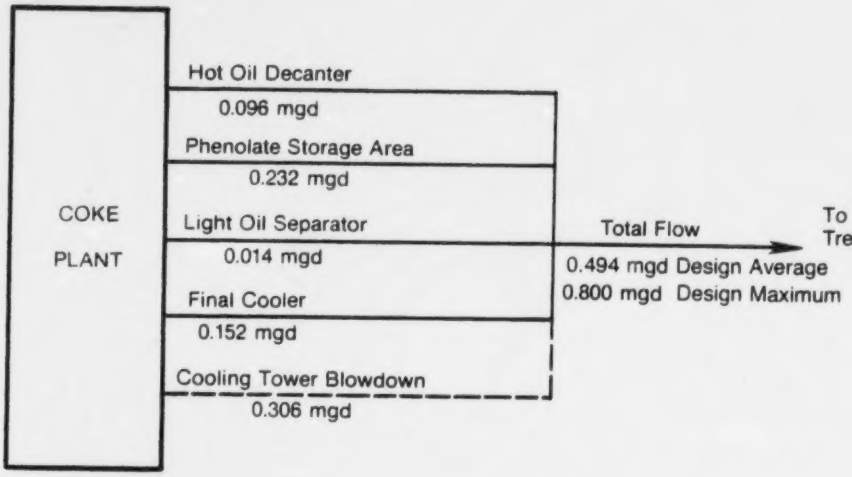

COKE PLANT
Hot Oil Decanter
0.096 mgd
Phenolate Storage Area
0.232 mgd
Light Oil Separator
0.014 mgd
Final Cooler
0.152 mgd
Cooling Tower Blowdown
0.306 mgd
Total Flow
0.494 mgd Design Average
0.800 mgd Design Maximum
To Wastewater Treatment Plant

Figure 2. Coke Plant Wastewater Streams

Factors considered which influenced the final decision were: capital cost, projected operations and maintenance costs, land requirements, future effluent limitations, sensitivity to plant upsets, and necessary level of operating expertise required. Activated carbon followed by alkaline chlorination was chosen as the appropriate treatment process. A Water Quality Management Permit to construct such a physical-chemical treatment facility was issued by the Pennsylvania Department of Environmental Resources (DER) on 25 April 1976.

Based upon the feasibility studies and concept report by The Chester Engineers, final detailed engineering and preparation of plans and specifications for the facility was undertaken by Roy F. Weston, Inc., Designers and Consultants. Engineering and construction was completed, and the plant subsequently began operations in September 1979.

WASTEWATER TREATMENT PLANT DESIGN BASIS

DESIGN PARAMETERS

As illustrated in Figure 2, the major sources of wastewater discharged to the treatment plant include:

Source	Design Flow
Hot Oil Decanter	0.096 mgd
Phenolate Storage Area	0.232 mgd
Light Oil Separator	0.014 mgd
Final Cooler	0.152 mgd
Cooling Tower Blowdown	0.306 mgd
Total	0.800 mgd

The design characteristics of the combined flow to the treatment plant and NPDES discharge limitations are listed in Table 1.

DESIGN BASIS VS CURRENT CHARACTERISTICS

The basis for the hydraulic and parameter design of the treatment plant are compared with current operating characteristics in Table 2. It is important to note that the plant influent ammonia concentration is greater than three times the design basis. In addition, the influent pH is highly variable. The significance of these variances from the design basis is discussed in subsequent sections of this paper.

TABLE 1. DESIGN WASTEWATER CHARACTERISTICS COMBINED FLOW TO WWTP

		NPDES Discharge Limitations	
Parameter	Design Value	Average	Maximum
Flow	0.80 mgd	---	---
SS	100 mg/L (667 ppd)	--- (1,800 ppd)	--- (3,760 ppd)
NH_3	100 mg/L (667 ppd)	--- (560 ppd)	30 mg/L (1,120 ppd)
Phenol	300 mg/L (2,000 ppd)	0.1 mg/L (7 ppd)	0.2 mg/L (14 ppd)
CN-A	70 mg/L (467 ppd)	0.025 mg/L (5 ppd)	0.05 mg/L (10 (ppd)
O&G	135 mg/L (900 ppd)	--- (410 ppd)	10 mg/L (620 ppd)
pH	8.0	6 to 9	

TABLE 2. COMPARISON OF DESIGN VS OPERATING WASTEWATER CHARACTERISTICS

Parameter	Design Basis	Previous Conditions (1980-1981)	Current Conditions (1981-1982)
Flow, mgd	0.80	0.35	0.38
SS, mg/L	100.	69	135
NH_3, mg/L	100.	199	332
Phenol, mg/L	300.	69	88
CN-A, mg/L	70.	45	32
O&G , mg/L	135.	---	---
pH	8.0	8.0 to 9.0	8.0 to 9.0
SCN	---	255	322

EPA Form 2350-4 (4-80)
(PREVIOUSLY CIN. EPA FORM 337)
TYPING GUIDE SHEET

WASTEWATER TREATMENT PLANT DESCRIPTION

PROCESS DESCRIPTION

A block flow diagram illustrating the treatment process utilized by Shenango for the removal of oil and grease, ammonia, phenol, suspended solids, dissolved organics, and cyanides is shown in Figure 3.

All the wastewater streams, except the hot oil decanter overflow, initially are combined in an equalization basin. This basin has a capacity of 260,000 gallons (984 m^3) and a detention time of eight hours at the design flow of 0.80 mgd (3,028 m^3/d) (16.4 hours detention time at the current flow rate of 0.38 mgd [1,438 m^3/d]). The basin is divided into two sections to allow isolation of one portion of the basin for maintenance purposes. Each section of the equalization basin is equipped with a 3 hp, single-speed mixer.

Underflow from the hot oil decanters is pumped to two dissolved air flotation (DAF) units for additional oil and grease removal. Any oil skimmings collected are recycled to the byproducts plant. Each DAF unit has a diameter of 9 ft (3 m), and detention time of 19 minutes at a design flow of 67 gpm (0.25 m^3/d). The surface loading rate for the DAF units is 1,500 gpd/sq ft (61 $m^3/m^2 \cdot d$). The underflow from the DAF units is pumped to the equalization basin, and combined with the other four waste streams at that point.

The combined flow from the equalization basin is pumped to two 35-ft (11.6 m) diameter clarifiers for suspended solids removal. The equalization basin discharge pumps may be operated manually, or operated automatically according to level controls in the basin. The detention time in each clarifier is six hours, and the overflow rate is 420 gpd/sq ft (17 $m^3/m^2 \cdot d$) at the design flow rate of 280 gpm (1.1 m^3/d). The underflow from the clarifiers is dewatered via a 4.5 ft (1.5 m) diameter (85 sq ft [7.9 m^2] of surface filtration) cloth vacuum filter. The sludge cake generated is hauled to a landfill for ultimate disposal.

The overflow from the clarifiers flows by gravity into a holding tank, and is subsequently pumped to two dual media pressure filters for additional suspended solids removal. The 10 ft (3.3 m) diameter filters are downflow units with a design flow-through rate of 7 gpm/sq ft (4.75 $L/m^2 \cdot s$) of filter surface area. The filters are utilized to prevent solids-clogging problems and decreased efficiencies in the downstream activated carbon columns. The effluent from the filters flows into an 18,000

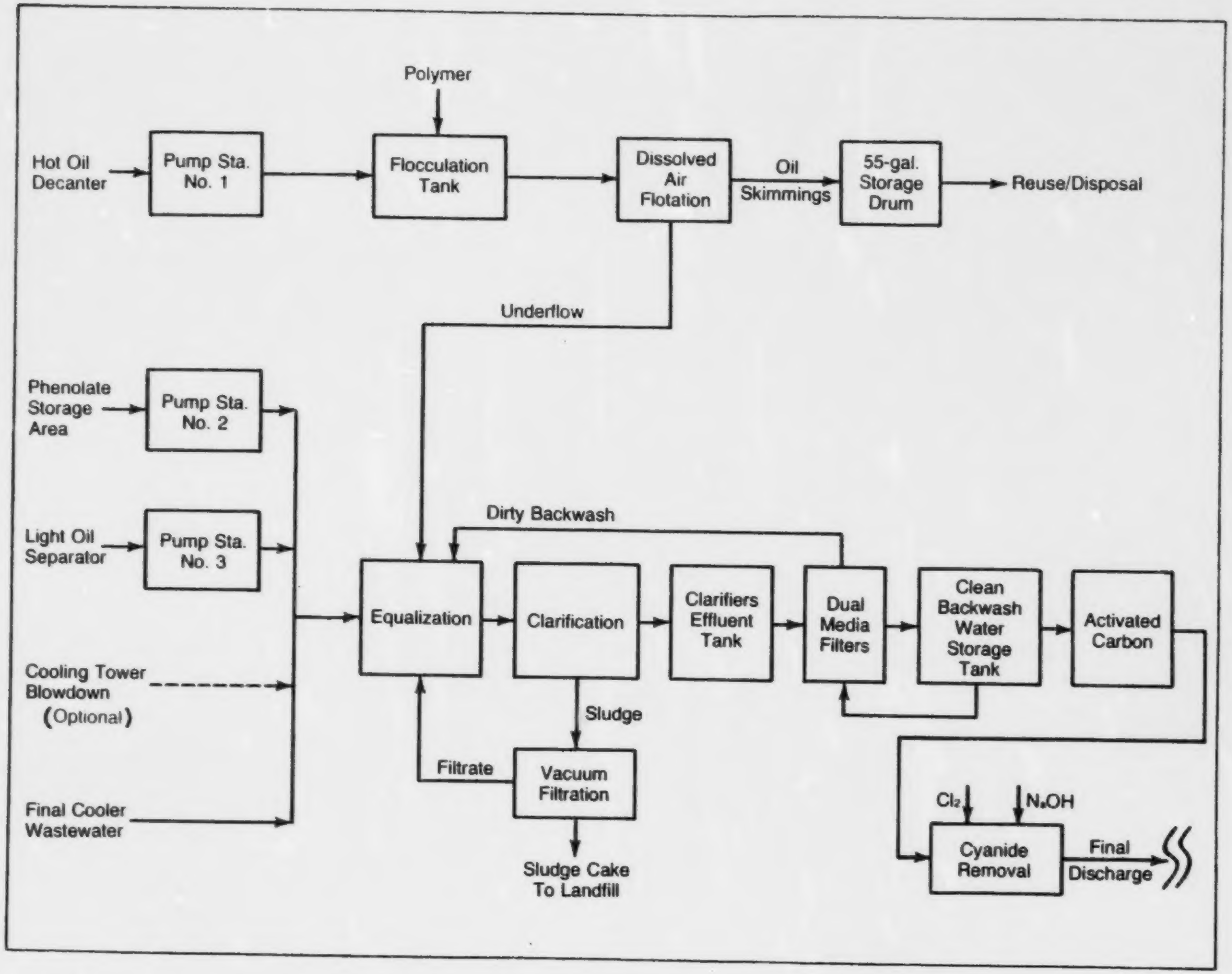

Hot Oil Decanter
Pump Sta. No. 1
Polymer
Flocculation Tank
Dissolved Air Flotation
Oil Skimmings
55-gal. Storage Drum
Reuse/Disposal
Underflow
Phenolate Storage Area
Pump Sta. No. 2
Light Oil Separator
Pump Sta. No. 3
Cooling Tower Blowdown (Optional)
Final Cooler Wastewater
Dirty Backwash
Equalization
Clarification
Clarifiers Effluent Tank
Dual Media Filters
Clean Backwash Water Storage Tank
Activated Carbon
Sludge
Filtrate
Vacuum Filtration
Sludge Cake To Landfill
Cl₂
N₂OH
Cyanide Removal
Final Discharge

Figure 3. Block Flow Diagram Wastewater Treatment System
Shenango Incorporated
Pittsburgh, Pennsylvania

gallon (68 m^3) carbon feed/backwash water storage tank. This tank is the water supply source for filter backwash water. Dirty backwash water is routed back to the plant equalization basin.

Filtered wastewater is pumped from the backwash water storage tank to the activated carbon system. Activated carbon utilized in the system is furnished through a service agreement with the Calgon Corporation. The system consists of two activated carbon columns operated in series to remove phenol and other dissolved organics that might be present. The carbon columns are located ahead of the cyanide removal system to minimize the formation of chlorinated hydrocarbons.

The effluent from the carbon columns flows to the cyanide removal unit operation. The cyanide system is a single-stage alkaline chlorination process that oxidizes cyanide to cyanate. The effluent from the carbon columns initially discharges into two 12-ft (4 m) diameter chlorine oxidation tanks where caustic (NaOH) is added to raise and maintain the wastewater pH at 9.0, and chlorine (Cl_2) is simultaneously added to oxidize cyanide to cyanate. The detention time in each tank at a design flow of 0.4 mgd (1,514 m^3/d) is one hour. Caustic and chlorine addition is automatically controlled based on pH and ORP (oxidation reduction potential) levels respectively in the oxidation tanks. Chlorine is supplied to the wastewater treatment plant via 55 ton (49,900 kg) or 90 ton (81,720 kg) railroad cars although ton cylinders are utilized during railroad car transfer periods. The liquid chlorine is transferred from the tank cars, passed through evaporators, and then fed via chlorinators to the oxidation tanks. The effluent from the oxidation tanks is then discharged as final effluent.

OPERATING EXPERIENCES

ACTIVATED CARBON SYSTEM

The Calgon activated carbon system consists of two 40,000 pound (18,160 kg) carbon vessels which are operated in series. The system was first placed on line in September 1979 and has operated efficiently with only relatively minor difficulties. These difficulties included premature phenol breakthrough and carbon fines breakthrough immediately following a carbon transfer.

Based on the validation study conducted during the carbon system design, it was estimated that the carbon usage rate would be approximately 20 pounds (9 kg) of carbon per 1,000 gallons (3.8 m^3) of wastewater for phenol levels averaging 159 mg/L at a pH of 7.0 to 8.0. At a current average flow rate of approximately 0.38 mgd (1,438 m^3/d), carbon breakthrough would be expected approximately every three days. Presently, the actual wastewater has a phenol concentration well below the design limits and, consequently, the phenol breakthrough only occurs approximately every seven days.

After several months of operation, an unusual trend began to emerge. In several instances immediately following a carbon transfer, the polished effluent would indicate phenol breakthrough. A detailed survey of the situation revealed a two-fold problem. First, an accumulation of solidified carbon had developed in the bottom (three to six feet) of the column. Secondly, the high wastewater pH led to a very low phenol adsorption by the carbon.

Although the reason for the solidification of the carbon was never discovered, it has been projected that mechanical failure in the carbon column underdrain system led to channeling of the wastewater. This channeling in turn permitted a portion of the carbon bed to solidify. A further study of the pH fluctuations revealed the following: although the carbon system is designed to operate at a pH of 7.0 to 8.0, the wastewater feed into the carbon system is not pH controlled. Depending on occurrences upstream of the facility, the pH can vary from 6.0 to 12.0, although such extreme variations are unusual. Since the alkaline chlorination system following the carbon system was operating at a pH of 10.0 to 11.0 at the time, attempts were made to keep the wastewater pH greater than 10.0 so that less caustic would be required. Studies performed by Calgon*, however, indicated a decrease in carbon efficiency as the pH increased above 9.0, and severe upsets when the pH exceeded 11.0. According to Calgon's report, "this phenomenon is expected due to the ionization of the phenol molecule at a high pH. The ionic form of the phenol molecule is very poorly adsorbed by the activated carbon." Thus, as we can see from Table 3, as the pH increases from 9.0 to 11.0, the percentage of molecular phenol decreases from 90 to 10. At a pH of 11.0, only 10 percent of the phenol will be in a molecular form. This results in approximately only 50 percent phenol adsorption as the wastewater reaches the discharge point of the first column. As further stated by Calgon, "when the molecular form represents only a small percentage of the total phenol content, the chemical equilibrium kinetics add to the adsorption kinetics to extend the length of the mass transfer zone and increase the probability of phenol leakage to the effluent."

---

*Letter from A.J. Roy and W.M. Rogers, Calgon Corporation to James R. Zwikl, Shenango, Inc., 12 May 1980.

TABLE 3. RELATIONSHIP BETWEEN pH AND PERCENTAGE OF MOLECULAR PHENOL PRESENT*

pH	Approximate Percent of Molecular Phenol Present
9	90
10	50
11	10

*Letter from A.J. Roy and W.M. Rogers, Calgon Corporation to James R. Zwikl, Shenango, Inc., 12 May 1980.

Excursions in pH above 11.0 can cause severe operational problems if a carbon bed has been well loaded with phenol previously. Re-equilibrium to a lower phenol concentration can cause desorption of previously adsorbed phenol, and produce effluent levels in excess of those found in the influent. Figure 4 graphically illustrates the relationship between phenol adsorption and pH which was observed over a consecutive three week span*. As can be observed, an increase in pH above 10.0 causes a corresponding increase in effluent phenol levels, while a decrease in pH to less than 10.0 causes a similar decrease in effluent concentrations.

Decreasing the pH levels to less than 8.5 at this installation, however, does not increase the operational efficiency of the carbon system. As a result, the system pH is controlled between 8.5 and 9.5 to obtain the most efficient and economical utilization of activated carbon.

CHLORINATION SYSTEM

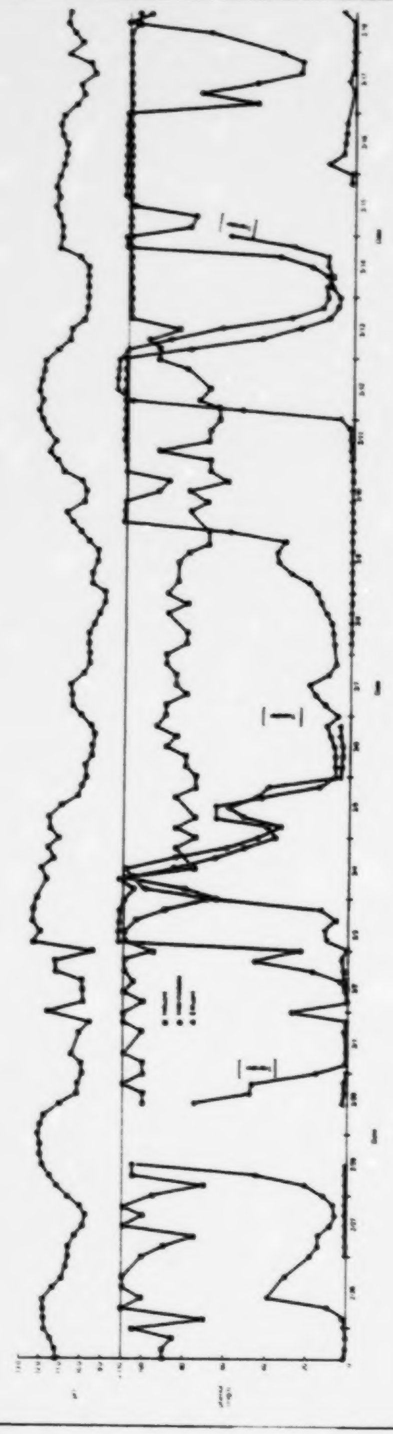
The alkaline chlorination system is a single-stage process designed to oxidize cyanide to cyanate.

The system consists of two completely mixed 15,000 gallon (56 m^3) cyanide oxidation tanks operated in parallel, two 8,000-pound (3,632 kg) per day evaporators (1 operating and 1 spare), two ejectors, and a 35,000 gallon (132 m^3) caustic storage tank with associated proportional feed pumps. The chlorine is supplied as a liquid from either a 55 ton (49,900 kg) or 90 ton (81,720 kg) railroad tank car which is located on a track adjacent to the chlorination building. Stand-by one ton (908 kg) cylinders of chlorine are available during those periods when railroad cars are switched. Air padding of the chlorine car is not required.

The alkaline chlorination system was designed to operate as follows: partially treated wastewater is fed in equal volumes into the bottom of each oxidation tank. Continuous readout ORP and pH probes located near the top of each tank measure and record both values on the main control panel. The pH recording controllers modulate the caustic pumps to maintain the proper pH levels within the oxidation tanks. Presently, a pH of 9.0 to 9.5 is maintained. The ORP recording controller regulates the amount

---

*Letter from A.J. Roy and W.M. Rogers, Calgon Corporation to James R. Zwikl, Shenango, Inc., 12 May 1980.



[1] Letter from A.J. Roy and W.M. Rogers, Calgon Corporation to James R. Zwikl, Shenango, Inc., 12 May 1980

Figure 4. Relationship Between pH and Phenol Concentration

of chlorine gas injected into the system through the ejectors. Laboratory analyses performed on the actual wastewater indicate that maintaining an ORP of approximately 120 to 180 mv should provide sufficient oxidation of cyanide to cyanate.

To date, efforts to place the system in the fully automatic mode of operation have proven unsuccessful. Although the pH control system has operated efficiently in the automatic mode, the ORP control system has not. The ORP system operation becomes very erratic within 4 to 48 hours after being placed in the automatic mode. It appears as though some interfering compounds inhibit the automatic operation of the ORP sensing and, consequently, the chlorine feed controller instrumentation.

The cyanide oxidation system is currently being operated in the manual mode, with resultant effluent cyanide "A" levels equalling or approaching the design limits while attempts are being made to resolve the problem. Several sets of bench-scale and full-scale tests have been performed in order to identify an ORP/cyanide oxidation relationship. A curve similar to that indicated in Figure 5 would be expected to characterize the cyanide, alkaline chlorination process. Bench-scale tests of composite carbon column effluent samples were conducted at system pH's of 9.5 and 10.5. The test results are presented in Tables 4 and 5 and indicate that chlorine dosage rates of 2,000 mg/L or less should be sufficient to oxidize the cyanide to permitted levels. At the plant's current influent flow rate of 0.38 mgd (1,438 m^3/d), this is equivalent to 6,300 ppd (2,858 kg/d) of chlorine, which is well within the treatment plant's chlorination system capacity. Unfortunately, graphical analysis of ORP (i.e., cyanide levels), and chlorine feed rate data collected during full-scale field tests, have yielded a horizontal line with no distinct breakpoint, as shown in Figure 6, indicating no consistent relationship exists between these parameters. Therefore, it appeared that ORP was not a viable parameter for monitoring and controlling the cyanide oxidation system in our process.

Since attempts to correlate ORP levels with cyanide "A" levels that are consistently below 2.5 mg/L have not proven totally successful, additional means to permit quick, accurate and frequent analyses of cyanide "A" in the influent and effluent chlorination system streams are required. A continuous readout, online cyanide "A" monitor is currently under development, and the first full-scale instrument is scheduled to be tested at Shenango's wastewater treatment facility in hopes that it will stabilize operation of the cyanide oxidation unit. Additional process studies are also being investigated.

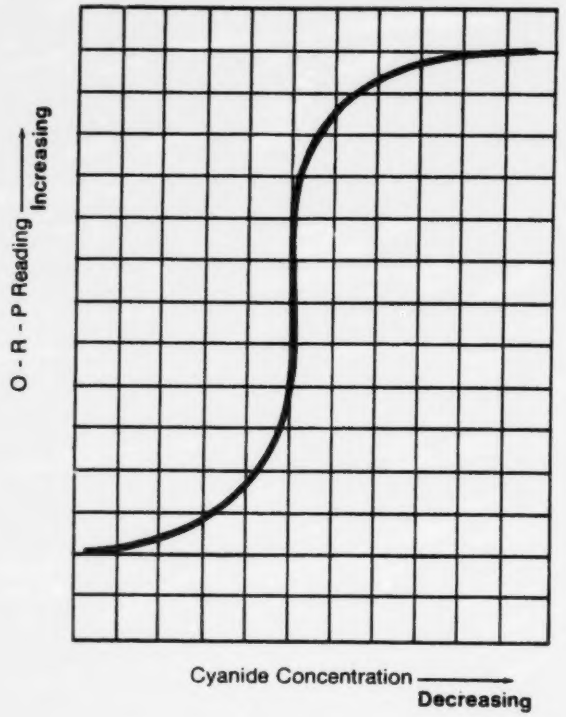


Figure 5. Typical ORP Versus Cyanide Concentration Relationship

TABLE 4. CHLORINE REQUIREMENT FOR CYANIDE OXIDATION

Parameter	Sample No. 1
Total Cyanide, mg/L CN	104
Amenable Cyanide, mg/L CN	97
Ammonia, mg/L N	54
Thiocyanate, mg/L CNS	240
ORP, mv	40

	Chlorine Addition, mg/L Cl_2			
	1500	2000	2500	3000
Sample No. 1 Analyses at 90 minutes and pH 9.5				
ORP, mv	140	180	490	520
Total Cyanide, mg/L CN	15.0	10.0	7.2	7.4
Amenable Cyanide, mg/L CN	8.2	3.2	<0.5	<0.5
Ammonia, mg/L N	50	18	2	1
Thiocyanate, mg/L CNS	38	5	<1	<1
Sample No. 1 Analyses at 90 minutes and pH 10.5				
ORP, mv	60	120	510	610
Total Cyanide, mg/L CN	10.0	8.8	6.2	6.2
Amenable Cyanide, mg/L CN	3.2	2.0	0.0	0.0
Ammonia, mg/L N	48	15	<1	<1
Thiocyanate, mg/L CNS	58	5	<1	<1

TABLE 5. CHLORINE REQUIREMENT FOR CYANIDE OXIDATION

Parameter	Sample No. 2	Sample No. 3
Total Cyanide, mg/L N	83	96
Amenable Cyanide, mg/L CN	77	88
Ammonia, mg/L N	35	33
Thiocyanate, mg/L CNS	310	290
ORP, mv	---	20

Sample No. 2 Analyses at 90 minutes and pH 9.5

	Chlorine Addition, mg/L Cl_2				
	1200	1500	2000	2500	3000
ORP, mv	100	120	140	320	410
Total Cyanide, mg/L CN	8.6	6.0	6.2	6.2	6.2
Amenable Cyanide, mg/L CN	1.8	0.2	0.4	---	---
Ammonia, mg/L N	34	35	14	2	2
Thiocyanate, mg/L CNS	190	72	<5	<5	<5
Sample No. 3 Analyses at 90 minutes and pH 9.5					
ORP, mv	---	130	220	400	460
Total Cyanide, mg/L CN	---	7.6	---	---	---
Amenable Cyanide, mg/L CN	---	0.0	---	---	---
Ammonia, mg/L N	---	33	23	4	2
Thiocyanate, mg/L CNS	---	57	5	5	---

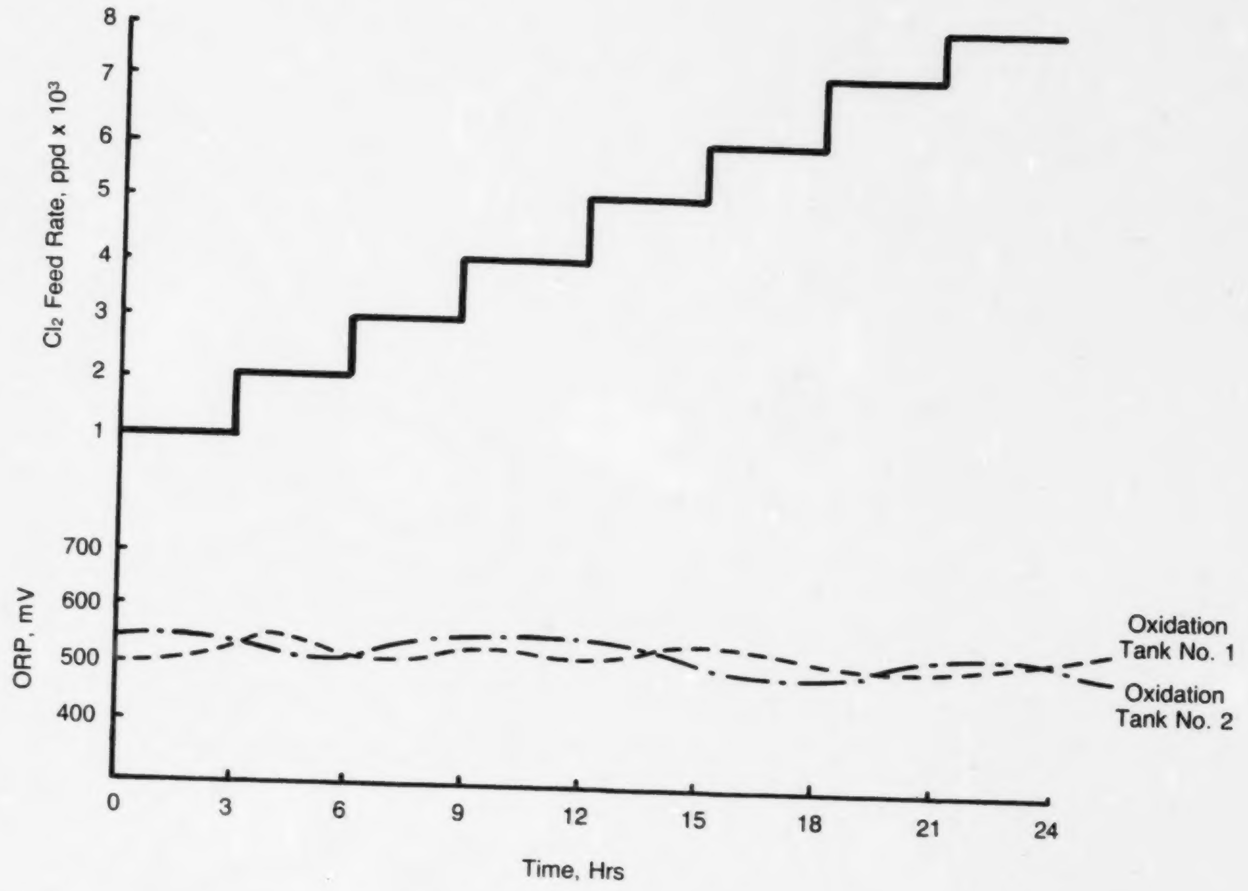


Figure 6. Cyanide Oxidation Field Test Results

SCALING

In early 1982 operating problems began to surface with the chlorine injector pumps. When the pumps were disassembled for maintenance it was discovered that all the wetted parts of the pump were coated with a grayish-white substance. In addition, the chlorine oxidation tanks were also found to be coated with a similar type of substance which was approximately 1/4-in. (0.635 cm) thick. Laboratory analyses revealed that the deposited material was calcium carbonate. Shortly thereafter it was also discovered that the chlorine-ejector water supply lines were reduced in diameter by approximately 1 to 2 in. (2.5-5 cm) due to scale buildup.

Further analyses were conducted to determine the scaling potential of the wastewater in the oxidation tools through the use of the Langelier Saturation Index (LSI). An LSI of +1.7 was calculated, indicating that the wastewater has a tendency to form scale.

Analyses also confirmed a decrease in total hardness across the oxidation tanks. Calcium precipitates as calcium carbonate, thus explaining the increase in suspended solids in the final plant effluent.

Several options are available as possible solutions to the scaling problem. These include: determining possible process changes upstream of the treatment facility; precipitating the column in the clarifiers; chemically neutralizing the wastewater through the use of a deposit control agent; or reducing the system pH in an attempt to retard the formation of scale.

The initial alternative chosen consisted of lowering the pH from 10.5 to 9.0. This is the simplest and most cost effective means of attempting to regulate the formation of scale, and is currently being evaluated.

CHEMICAL AVAILABILITY

The basic reactions which occur in the alkaline chlorination process require the use of large quantities of caustic and chlorine. Unfortunately, the market for these two chemicals has fluctuated dramatically over the past several years. Since both caustic and chlorine are produced simultaneously, the demand for either chemical influences the cost and availability of the other.

The wastewater treatment facility consumes approximately three to four tons (2,724 to 3,632 kg) of chlorine and 1,400 gallons (5.3 m^3) of caustic daily. Therefore, both the cost and availability of either chemical will dramatically affect both the efficiency and operating costs of the facility.

Since the plant start-up in September 1979, the cost of chlorine has actually decreased by 30 percent, while the price of caustic has increased by 106 percent. The overall effect is a net chemical cost increase of $1.28/1,000 gallons of wastewater treated.

WASTEWATER TREATMENT PLANT PERFORMANCE

CURRENT PERFORMANCE

The current operating performance of the treatment plant is indicated in Table 6. Excellent phenol removal in excess of 99 percent is consistently obtained from the system.

As detailed in this paper, however, problems still remain to be overcome in the efficient operation of the alkaline chlorination portion of the plant. It is anticipated that the efficient control of the chlorine feed which may be obtained through the use of the continuous cyanide "A" analyzer will increase the cyanide "A" removal efficiency from 87 to 96 percent.

Influent ammonia levels, as stated earlier, are approximately 200 percent higher than originally anticipated. As a result, an insufficient amount of excess chlorine is available to entirely oxidize the ammonia and, thus, a lower than anticipated removal efficiency is obtained.

The suspended solids removal data of 77 percent is very misleading. A suspended solids removal of approximately 100 percent is generally achieved between the clarifiers, dual-media filters, and activated carbon columns. The precipitation of calcium carbonate (as previously discussed) in the alkaline chlorination system is responsible for the apparent decreased efficiency in solids removal.

Thiocyanate removals of 72 percent have also been observed as the thiocyanate is oxidized to cyanate.

BPT PERFORMANCE

The plant effluent characteristics are compared with the current NPDES and Best Practicable Control Technology Currently Available (BPT) discharge limits for by-product coke plants in Table 7. It can be observed that except for cyanide "A" the

TABLE 6. TREATMENT PLANT PERFORMANCE

Parameter	Influent Average	Influent Range	Effluent Average	Effluent Range	Percent Removal Average	Percent Removal Range
Flow, mgd	0.38	---	0.38	---	N/A	---
SS, mg/L	135	15- 472	21	3- 53	77	19- 98
NH_3, mg/L	332	74-1,233	175	21-941	52	2- 83
Phenol, mg/L	88	35- 238	0.40	0.004- 1.4	>99.5	98.3- 99.9
CN-A, mg/L	32	4- 102	4.0	0- 12	87	58-100
pH	8.8	2- 12	9.0		N/A	---
SCN, mg/L	322	106- 484	102	11-338	72	49-96

TABLE 7. TREATMENT PLANT PERFORMANCE VS NPDES PERMIT AND PROMULGATED BAT/BCT LIMITS

Parameter	Past Discharge Levels (1980-1981) mg/L (ppd)		Present Discharge Levels (1981-1982) mg/L (ppd)		NPDES Limits mg/L (ppd)		BPT Limits* (ppd)		BAT/BCT Limits* (ppd)	
	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.
SS	15.6 (44.1)	30 (101)	21.3 (64.1)	53 (173)	--- (1,800)	--- (3,760)	393	759	(393)	(759)
O&G	--- ---	--- ---	---	---	--- (410)	10 (620)	33	98	(33)	(98)
NH_3-N	144 (427)	569 (1,604)	175 (545)	941 (2,606)	--- (560)	30 (1,120)	274	822	(97)	(194)
CN-A	5.9 (17.9)	17.2 (79)	4.0 (9.7)	12.2 (35)	0.025 (5)	0.05 (10)	66	197	---	---
Phenol	0.7 (2.0)	3.8 (10.9)	0.4 (1.3)	1.4 (4.2)	0.1 (7)	0.2 (14)	4.5	13.5	(0.13)	(0.26)
pH	9		6 to 9		6 to 9		6 to 9		6 to 9	
Benzene	0.0046 (0.013)	--- ---	---	---	---	---	---	---		(0.06)
Naphthalene	<0.010 <(0.030)	--- ---		---	--- ---	--- ---	--- ---	--- ---	---	--- (0.06)
BAP	<0.010 <(0.030)	--- ---	---	---	--- ---	--- ---	--- ---	--- ---	---	(0.06)

*At production level = 1,500 T/Day - Based on regulations promulgated on 5/27/82 (40 CFR Part 420).

plant is meeting current NPDES discharge limits. In addition, the plant discharge is achieving BPT limits with the exception of ammonia level exceedances.

BAT/BCT PERFORMANCE

Table 7 also compares the current discharge levels with the recently promulgated Best Available Technology Economically Achievable/Best Conventional Technology* (BAT/BCT) limits for by-product coke plants. As can be readily observed, the plant does not meet BAT or BCT limits for ammonia or phenol. The limits for benzene, benzo(a)pyrene, and napthalene are currently being met based on limited data.

It does not appear economically feasible to sufficiently reduce the discharge of phenol and ammonia at this facility.

The BAT limits for phenol are compared to treatment plant performance on a lb phenol/1,000 lb coke basis below:

	BAT Limit	WWTP Effluent
Maximum	0.0000859 lb phenol/ 1,000 lb coke	0.00660 lb phenol/ 1,000 lb coke
Average	0.0000430 lb phenol/ 1,000 lb coke	0.00068 lb phenol/ 1,000 lb coke

The treatment plant effluent values reported are based on long term data collected by Shenango and represent discharge levels following treatment by 80,000 pounds (36,320 kg) of activated carbon. Although a minimum of 0.000007 lb phenol/1,000 lb coke has occasionally been achieved at the physical-chemical plant, the present system is not capable of achieving such a discharge limit over prolonged periods of operation. In fact, the average discharge level is 16 times higher than the BAT limits.

Currently higher than anticipated influent ammonia levels are being observed at the treatment plant even though a free and fixed ammonia still is presently operating efficiently in the by-products plant. This has resulted in the inability to achieve discharge limits. The proposed BAT ammonia level of 0.0322 lb ammonia-N/1,000 lb coke is presently being exceeded by a factor of 9 (0.2868 lb NH_3-N/1,000 lb coke). Considerable further investigation is required before this problem can be resolved.

---

*As published in 40 CFR Part 420, 27 May 1982.

PRIORITY POLLUTANTS

As previously shown in Figure 3, Shenango's wastewater treatment scheme includes activated carbon followed by alkaline chlorination. This was done to minimize the formation of chlorinated hydrocarbons in the treatment plant effluent.

Analyses were conducted across the treatment system to determine the ability of the facility to remove priority pollutants. Five days of samples were collected and composited at the locations shown in Table 8. As shown in the table, only 11 organic priority pollutants were detectable in the influent to the activated carbon system. Adsorption by activated carbon removed the majority of pollutants with the exception of acrylonitrile, which was oxidized in the alkaline chlorination portion of the plant. The treatment facility showed 100 percent removal of the above listed organic priority pollutants with the exception of phenol, which was reduced in concentration by 99.3 percent.

The use of alkaline chlorination treatment did, however, cause the formation of chloroform. A concentration of 27.5 µg/L was measured in the chlorination system effluent. The mixture of the treatment plant effluent with the remaining facility wastewater, however, resulted in a chloroform concentration of <5 µg/L at the point of discharge to the Ohio River.

In 1979-1980, EPA conducted a coke plant wastewater treatment study* at Shenango's Coke & Iron facility. The pilot plant flow scheme utilized during the EPA study included alkaline chlorination followed by activated carbon which is reverse to the flow scheme utilized by Shenango. Priority pollutant sampling results from EPA's study are compared in Table 9 to those compiled by Shenango. The analytical results indicated that except for phenol, the concentration of organic priority pollutants in Shenango's effluent was less than or equal to the levels reported in the EPA study. The levels of acrylonitrile, chloroform, and 1,2-dichloroethene were particularly lower in Shenango's effluent than in EPA's pilot plant discharge.

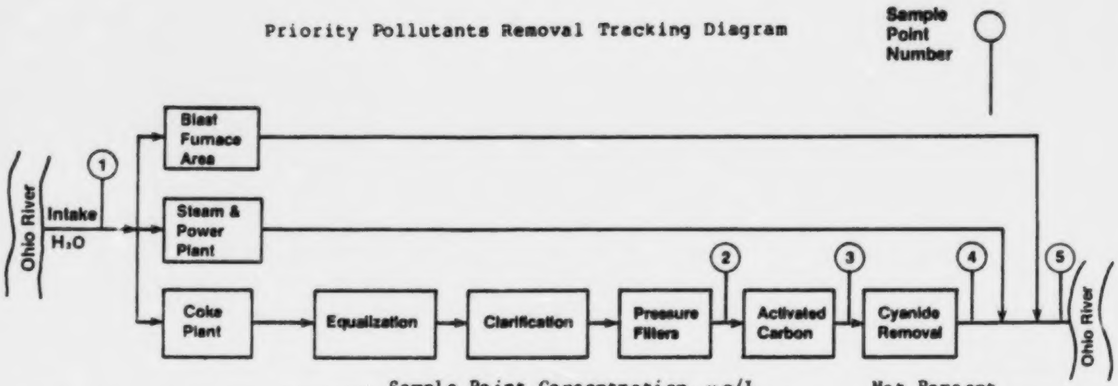
ECONOMICS

The capital cost required to construct Shenango's physical-chemical wastewater treatment facility was $2,300,000 in 1977-1979 dollars. Of this total, approximately $660,000 (29 percent)

---

*EPA Effluent Guidelines Division, Report No. EPA-600/2-81-053, Research and Development, Physical/Chemical Treatment of Coke Plant Wastewater, April 1981.

TABLE 8. PRIORITY POLLUTANTS REMOVAL TRACKING DIAGRAM


Priority Pollutants Removal Tracking Diagram

Sample Point Number
Ohio River
Intake
H_2O
1
Blast Furnace Area
Steam & Power Plant
Coke Plant
Equalization
Clarification
Pressure Filters
2
Activated Carbon
3
Cyanide Removal
4
5
Ohio River

Parameter	Sample Point Concentration, μg/L 1	2	3	4	5	Net Percent Removal
Acrylonitrile	<100	6,000	5,000	<100	<100	100
1,2-Dichloroethane	<5	60	ND	<10	<5	100
Benzene	<5	5,835	80	4.6	<5	100
Toluene	<5	2,060	ND	<10	<5	100
Napthalene	<10	3,610	1.1	<10	<10	100
Acenaphthylene	<10	150	ND	<10	<10	100
Phenanthrene	<10	19	ND	<10	<10	100
Phenol	<25	29,000	417	209	<25	100
Fluorene	<10	9	ND	<10	<10	100
Anthracene	<10	9	ND	<10	<10	100
Methylene Chloride	<5	ND	9	<10	<5	100
Chloroform	<5	---	---	27.5	<5	
2,4,6-Trichlorophenol	<25	---	---	24	<25	

TABLE 9. COMPARISON OF SHENANGO'S AND EPA'S PLANT PRIORITY SAMPLING RESULTS

METALS

Parameter	Shenango WWTP	EPA Pilot Plant* Average	EPA Pilot Plant* Range
Arsenic, mg/L As	0.068	0.072	0.03 - 0.22
Aluminum, mg/L Al	0.1	1.3	0.8 - 1.9
Barium, mg/L Ba	<0.1	0.007	0.04 - 0.12
Calcium, mg/L Ca	17	15	11 - 20
Copper, mg/L Cu	1.85	0.04	0.01 - 0.08
Iron, mg/L Fe	2.38	3.39	0.0 - 7.7
Magnesium, mg/L Mg	4.2	4.1	3.5 - 4.9
Manganese, mg/L Mn	0.05	0.34	0.19 - 0.50
Nickel, mg/L Ni	0.12	0.19	0.2 - 0.05
Selenium, mg/L Se	0.049	0.24	0.13 - 0.34
Sodium, mg/L Na	3,150	6,417	3,900 -8,000
Zinc, mg/L Zn	0.14	0.12	0.08 - 0.22
Mercury, mg/L Hg	<0.002	0.0023	0.0003-0.0061
VOLATILE COMPOUNDS			
Acrolein, μg/L	<100	---	---
Acrylonitrile, μg/L	<100	2,015	ND** -8,500
Benzene, μg/L	4.6	12	ND
Bromomethane, μg/L	<10	---	---
Bromodichloromethane, μg/L	<10	---	---
Bromoform, μg/L	<10	ND	ND
Carbon Tetrachloride, μg/L	<10	ND	ND
Chlorobenzene, μg/L	<10	ND	ND
Chloroethane, μg/L	<10	---	---
2-Chloroethylvinyl ether, μg/L	<10	---	---
Chloroform, μg/L	27.5	630	ND -3,200
Chloromethane, μg/L	<10	---	---
Dibromochloromethane, μg/L	<10	ND	ND

*EPA Effluent Guidelines Division, Report No. EPA-600/2-81-053, Research and Development, Physical/Chemical Treatment of Coke Plant Wastewater, April 1981.

**ND - Not Detected.

TABLE 9. (continued)

Parameter	Shenango WWTP	EPA Pilot Plant*	
		Average	Range
VOLATILE COMPOUNDS (CONTINUED)			
1,1-Dichloroethane, μg/L	<10	---	---
1,2-Dichloroethane, μg/L	<10	25	ND-64
1,1-Dichloroethene, μg/L	<10	ND	ND
trans-1,2-Dichloroethene, μg/L	<10	ND	ND
1,2-Dichloropropane, μg/L	<10	---	---
cis-1,3-Dichloropropene, μg/L	<10	---	---
trans-1,3-Dichloropropene, μg/L	<10	---	---
Ethylbenzene, μg/L	<10	ND	ND
Methylene chloride, μg/L	<10	---	---
1,1,2,2-Tetrachloroethane, μg/L	<10	ND	---
Tetrachloroethene, μg/L	<10	---	---
1,1,1-Trichloroethane, μg/L	<10	---	---
1,1,2-Trichloroethane, μg/L	<10	---	---
Trichloroethene, μg/L	<10	---	---
Trichlorofluoromethane, μg/L	<10	---	---
Toluene, μg/L	<10	19	ND-60
Vinyl chloride, μg/L	<10	---	---
ACID EXTRACTABLES			
4-Chloro-3-methylphenol, μg/L	<25	---	---
2-Chlorophenol, μg/L	<25	ND	ND
2,4-Dichlorophenol, μg/L	<25	ND	ND
2,4-Dimethylphenol, μg/L	<25	ND	ND
2,4-Dinitrophenol, μg/L	<250	---	---
2-Methyl-4,6-dinitrophenol, μg/L	<250	---	---
2-Nitrophenol, μg/L	<25	---	---
4-Nitrophenol, μg/L	<25	---	---
Pentachlorophenol, μg/L	<25	ND	ND
Phenol, μg/L	<209	ND	ND
2,4,6-Trichlorophenol, μg/L	<24	ND	ND
BASE-NEUTRAL EXTRACTABLES			
Acenaphthlene, μg/L	<10	ND	ND
Acenaphthylene, μg/L	<10	0.08	ND-1
Anthracene, μg/L	<10	0.3	ND-3
Benzo(a)anthracene, μg/L	<10	ND	ND
Benzo(b)fluoranthene, μg/L	<10	---	---
Benzo(k)fluoranthene, μg/L	<10	---	---
Benzo(a)pyrene, μg/L	<10	ND	ND

TABLE 9. (continued)

BASE-NEUTRAL EXTRACTABLES (CONTINUED)

Parameter	Shenango WWTP	EPA Pilot Plant*	
		Average	Range
Banzo(g,h,i)perylene, μg/L	<25	ND	ND
Benzidine, μg/L	<10	ND	ND
Bis(2-chloroethyl)ether, μg/L	<10	---	---
Bis(2-chloroethoxy)methane, μg/L	<10	---	---
Bis(2-ethylhexyl) phthalate, μg/L	<10	---	---
Bis(2-chloroisopropyl)ether, μg/L	<10	---	---
4-Bromophenyl phenyl ether, μg/L	<10	---	---
Butyl benzyl phthalate, μg/L	<10	---	---
2-Chloronaphthalene, μg/L	<10	---	---
4-Chlorophenyl phenyl ether, μg/L	<10	---	---
Chrysene, μg/L	<10	ND	ND
Dibenzo(a,h)anthracene, μg/L	<25	ND	ND
Di-n-butyphthalate, μg/L	<10	---	---
1,3-Dichlorobenzene, μg/L	<10	---	---
1,4-Dichlorobenzene, μg/L	<10	---	---
1,2-Dichlorobenzene, μg/L	<10	---	---
3,3'-Dichlorobenzidine, μg/L	<10	---	---
Diethylphthalate, μg/L	<10	---	---
Dimethylphthalate, μg/L	<10	---	---
2,4-Dinitrotoluene, μg/L	<10	ND	ND
2,6-Dinitrotoluene, μg/L	<10	---	---
Dioctylphthalate, μg/L	<10	---	---
1,2-Diphenylhydrazine, μg/L	<10	---	---
Fluoranthane, μg/L	<10	ND	ND
Fluorene, μg/L	<10	ND	ND
Hexachlorobenzene, μg/L	<10	ND	ND
Hexachlorobutadiene, μg/L	<10	---	---
Hexachloroethane, μg/L	<10	---	---
Hexachlorocyclopentadiene, μg/L	<10	---	---
Indeno (1,2,3-cd) pyrene, μg/L	<25	ND	ND
Isophorone, μg/L	<10	ND	ND
Naphthalene, μg/L	<10	1.3	ND-9
Nitrobenzene, μg/L	<10	---	---
N-Nitrosodimethylamine, μg/L	<10	---	---
N-nitrosodi-n-propylamine, μg/L	<10	---	---
N-Nitrosodiphenylamine, μg/L	<10	---	---
Pnenanthrene, μg/L	<10	0.3	ND-3
Pyrene, μg/L	<10	ND	ND
2,3,7,8-Tetrachlorodigenzon-p-dioxin, μg/L	ND	---	---
1,2,4-Trichlorobenzene, μg/L	<10	---	---

was required for mechanical equipment, and the remaining $1,640,000 (71 percent) was required for the actual plant construction.

Annual operating and maintenance costs have increased considerably since the plant start-up in September 1979. The major factor contributing to this dramatic increase has been the effects of inflation on the price of caustic (106 percent since September 1979) and activated carbon (45 percent since September 1979). In the first seven months of 1982, these two operating supplies accounted for approximately 62 percent of the monthly operating cost. A breakdown of the 1982 operating costs is presented in Table 10.

Based on 1982 cost figures through July, the treatment facility has an operating and maintenance cost of approximately $181,000 per month. This is an equivalent cost of $6.65/ton of coke at present reduced production rates, or $5.87/ton at 1981 production rates, which represent a more normal business condition. An increase in production costs in this magnitude significantly influences a company's ability to remain competitive in the open market.

When analyzed from a water through-put basis, the operating and maintenance costs are equivalent to $15.86/1,000 gallons ($4.19/m^3) of influent wastewater. Unfortunately, even with such a high operating cost, all of the BAT limits cannot be achieved even though BAT, or "state of the art" technology is currently being utilized by Shenango.

SUMMARY

In order to meet discharge limitations, and in anticipation of rapidly approaching BAT requirements in September 1979, Shenango Incorporated installed an activated carbon/alkaline chlorination wastewater treatment facility at its Neville Island Coke Plant. The optimization of the carbon system, along with the on-going attempts to effectively automate the chlorination system, has resulted in a treatment facility which can be considered BAT technology, but which cannot totally achieve BAT limitations.

Although the facility does an excellent job of removing organic priority pollutants, certain BAT limitations, such as phenol, cannot be achieved even though the carbon system removal efficiency consistently averages greater than 99.5 percent.

TABLE 10. OPERATING & MAINTENANCE COST DISTRIBUTION

Item	Cost/Month	Percent O&M Cost
Operating Labor	$ 26,600	14.7
Maintenance Materials and Services	16,200	9.0
Operating Supplies (Caustic, Chlorine, Carbon)	121,400	67.2
Laboratory Services	2,000	1.1
Electricity*	12,000	6.6
Miscellaneous	2,600	1.4
TOTAL	$180,800	100.0

*Based on a cost of $0.108/KWHr (weighted average of purchased and produced electricity).

When the effects of inflation from 1979 to 1982 on caustic and activated carbon are analyzed, the economic achievability of certain BAT limitations through physical/chemical treatment must be questioned. A treatment cost of greater than $15 per 1,000 gallons ($\$4/m^3$) of wastewater demands that cost/benefit considerations should be made before implementation of more stringent guidelines is imposed.

DISCLAIMER

Although the research described in this paper has been funded wholly or in part by the U.S. Environmental Protection Agency, it has not been subjected to Agency review and therefore does not necessarily reflect the views of the Agency and no official endorsement should be inferred.

NITRIFICATION KINETICS AS INFLUENCED BY COKE PLANT WASTEWATERS

by: Ronald D. Neufeld, PI
Professor of Civil Engineering
University of Pittsburgh
Pittsburgh, PA 15261

Jeffrey H. Greenfield
Graduate Research Assistant
University of Pittsburgh

ABSTRACT

The overall objective of this research is to conduct basic studies into possible causes of biological nitrification process instability as often observed in steel industry wastewaters, and in a longer term, to propose rational and pragmatic process and operational alternatives for nitrification in two sludge and one-sludge combined systems. The experimental approach taken to date is to evaluate the influence of elevated free ammonia levels, pH, elevated temperatures, cyanides, and certain trace organics that tend to pass through the carbonaceous reactor zone on the kinetic parameters that quantify nitrification. Theoretical calculations based on laboratory defined parameters are made which yield suggestions as to allowable concentrations of trace inhibitors, and operational strategies for stable nitrification of coke plant waste waters.

INTRODUCTION

There are many "advanced wastewater" treatment processes based on physical-chemical and biological techniques for the removal of wastewater ammonia, however, usually these processes are not often employed in industry due to economics, marginal overall removal efficiencies, and questionable technological application to specific industrial operations. Of the processes available for the removal of ammonia from steel industry wastewaters, engineered biological systems are the most pragmatic. Data from steel industry and other industrial operations indicate that a properly designed and operated biological nitrification facility is capable of reducing ammonia levels to less than 10 mg/L over extended periods of time. Biological nitrification processes, however, are known to exhibit unaccounted for upsets, and thus are considered in some industrial sectors as unreliable.

This research investigated possible causes of biological nitrification process instabilities as currently observed in coke plant and other industrial plant wastewater treatment facilities. Nitrification process instability can occur as a result of toxic inhibition as caused by an interaction of organics, free ammonia, elevated temperatures, pH, complexed and free cyanides, phenolics as well as by nonbiodegradable organics that pass through carbonaceous removal stages.

From laboratory data obtained on studies of nitrification process instability, conclusions with engineering calculations are presented to illustrate design and operational considerations enabling industry to meet EPA effluent restrictions for ammonia-nitrogen and phenolic compounds. The conditions utilized in this study were aimed at specifically assisting the coke plant segment of the Iron and Steel Industry.

Table 1 summarizes the BAT limitations, a technology level to be implemented by July 1, 1984 and the prior BPT effluent limitations for the Iron and Steel Industry and may thus be considered as the goal to be met by the industry.

OVERVIEW OF RESULTS

Experimental results to date show that unionized ammonia acts as a toxic inhibitor at levels in excess of 10 mg/L unionized ammonia. Quantification of the influence of unionized ammonia on biokinetics yields an expression similar to classical substrate inhibition models. Suggestions are made as to pH controls for systems treating high levels (greater than 250 mg/L) of total ammonia or systems experiencing large variations of total ammonia. (1).

Nitrification biokinetics are highly sensitive to elevated temperatures with rates of nitrification increasing as temperature increases to a maximum at about 30^oC, beyond which the overall rate of nitrification decreases. Suggestions were made as to a pragmatic temerature range to assure stable nitrification in commercial sized facilities. (2).

Free cyanide (CN_a) was the most toxic inhibitor investigated. Concentrations of free cyanide greater than 0.11 mg/L must be avoided for stable operation of biological nitrification processes. (3).

A comparison of the toxic effects of coke plant tar acid phenolics showed that this substance was of greater toxicity to nitrifiers than reagent grade phenol on an equal phenol concentration basis. The apparently more severe toxicity of the coal tar acids may be due to a few substances

TABLE 1

EFFLUENT LIMITATION GUIDELINES FOR THE BY-PRODUCT COKEMAKING SUBCATEGORY OF THE IRON AND STEEL INDUSTRY(a)

BAT EFFLUENT LIMITATIONS

POLLUTANT PARAMETER	MAXIMUM FOR ANY 1 DAY		AVERAGE OF DAILY VALUES FOR 30 CONSECUTIVE DAYS	
	Discharge Load (Kg/kkg) (lbs/1000 lb)	Discharge Conc. mg/l(b)	Discharge Load (Kg/kkg) (lbs/1000 lb)	Discharge Conc. mg/l
Ammonia-N	0.0543	65.1	0.0160	19.2
Cyanide	0.00638	7.6	0.00351	4.2
Phenols (4 AA-P)	0.0000638	0.08	0.0000319	0.04
Benzene	0.0000319	0.04		
Naphthalene	0.0000319	0.04		
Benzo(a)pyrene	0.0000319	0.04		

BPT EFFLUENT LIMITATIONS

	Discharge Load (Kg/kkg) (lbs/1000 lb)	Discharge Conc. mg/l (b)	Discharge Load (Kg/kkg) (lbs/1000/lb)	Discharge Conc. mg/l
TSS	0.253	303.4	0.131	157.1
Oil and Grease	0.0327	39.2	0.0109	13.1
Ammonia-N	0.274	328.5	0.0912	109.4
Cyanide	0.0657	78.8	0.0219	26.3
Phenols (4 AA-P)	0.00451	5.4	0.00150	1.8
pH within the range of 6.0 to 9.0				

Notes: (a) Federal Register, 1982
(b) Discharge concentration (for comparitive purposes) are based on effluent flows of 200 gal/ton of coke for BAT and BPT

EPA Form 2350-4 (4-80)
(PREVIOUSLY CIN. EPA FORM 287)
TYPING GUIDE SHEET

which may be in the liquid matrix, or a synergistic approach representing combinations of large numbers of substances as being toxic to nitrification. (4).

Experimental Approach

Nitrification biokinetics has been shown to follow classical Monod kinetics of the form:

$$v = V_{max}S/\ (K_m+S) \qquad (1)$$

where: V = rate of nitrification (t^{-1})

S = ammonia level in solution (mg/L)

V_{max}, K_m = system constants

In addition, for biological systems, the following system equation may be derived:

$$1/\theta = av - b \qquad (2)$$

θ = sludge age (days)

Where a = observed yield coefficient (g/g)

b = endogenous decay coefficient (day $^{-1}$)

The approach taken in this research, is to quantify the influence of inhibitors typical of coke plant wastewaters on the biokinetic parameters for nitrification. Toxic or biokinetic inhibition tends to alter the shape of the effluent ammonia vs. sludge age design curve which results from the combination of the above two equations.

The final form of data from this research are summary plots of the influence of parameters typical of coke plant waste waters on the biokinetic constants of nitrification, and on the system design curve for process nitrification. The conditions considered are free (or unionized) ammonia which acts as a "substrate inhibitor", free and complexed cyanides and thiocyanate, phenol and tri-methylated phenolics, pyridine, and elevated temperatures. For comparison purposes, a sample of coal tar acids was obtained from a local coke plant which, as indicated above, was found to be more toxic to nitrifiers when compared on an equal phenol (measured by 4-AA) basis.

Results of free ammonia inhibition have been published elsewhere, and will not be included in this paper (1). Details of trace substance interaction, and temperature interactions are included in prior reports to AISI (2,3,4). These results are summarized below.

Experimental Results of Elevated Temperatures on Nitrification Biokinetics

The experiments conducted were developed to quantify the influence of elevated temperatures on the defining parameters at a pH of 8.0. It should be noted that the data developed were for nitrifiers that were acclimated to the elevated temperature in continuous cultures; the data does not reflect the shock effects of temperature, but rather does reflect steady-state bio-kinetics for essentially pure nitrifiers.

Figure 1 is a summary plot of maximum nitrification rate (Vm) as a function of temperature. This Figure shows that at a pH = 8.0, Vm is constant at 1.256 $gNH_3/gVSS$-Day in the range of 22°C and 30°C and then decreases to a value approximately equal to zero at T = 45°C. This decrease in Vm was found to be described by the equation:

$$Vm = 3.78 - 0.084 (T) \qquad (3)$$

for $30^\circ C \geq T^\circ C \geq 45^\circ C$

The numerical value for the Michaelis-Menten parameter "K_m" was also evaluated with temperature as shown on Figure 2. In a qualitative sense, as the K_m value decreases, the kinetic curve is pushed to the left indicating an increased rate of nitrification at a constant design value of ammonia level in the effluent. As the K_m value increases, the kinetic curve is pushed to the right, indicating a relatively lower rate of nitrification, thus requiring an increased sludge age for stable operations at the same effluent ammonia level.

From the experiments conducted, the value of K_m was found to decrease in the temperature range of 22°C to 30°C in accordance with the equation:

$$\text{Log } (K_m) = 1.53 - 0.0315 (T) \qquad (4)$$

and at temperatures greater than 30°C, K_m was found to follow the expression:

$$\text{Log } (K_m) = -1.8829 + 0.08228 (T) \qquad (5)$$

where: T = temperature, (°C)
K_m = constant, (mg/L ammonia)

A similar evaluation was made of observed yield coefficient. For the temperature range of 22°C to 30°C, this coefficient was a constant as:

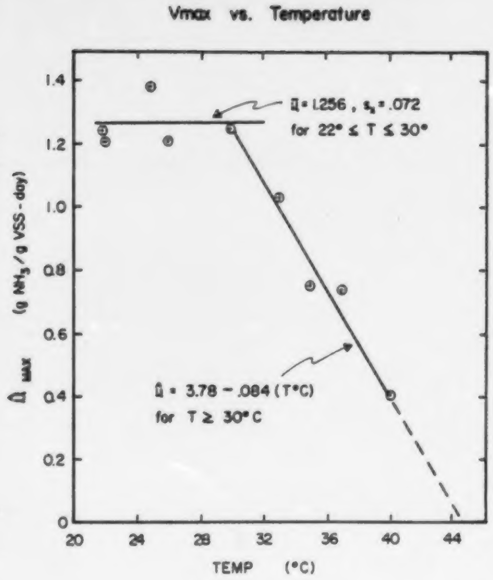


FIGURE 1

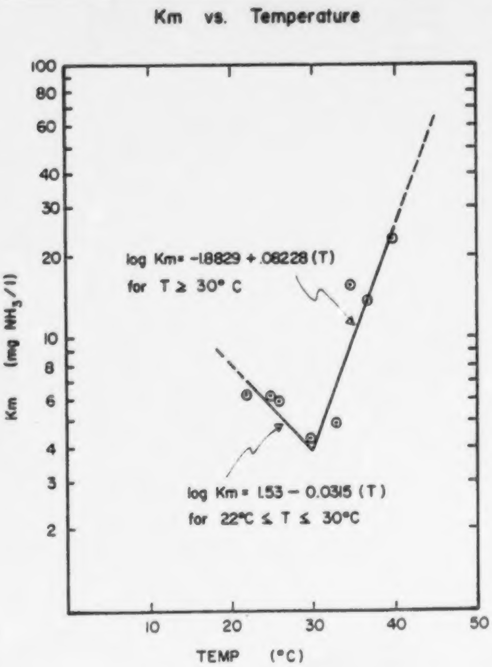


FIGURE 2

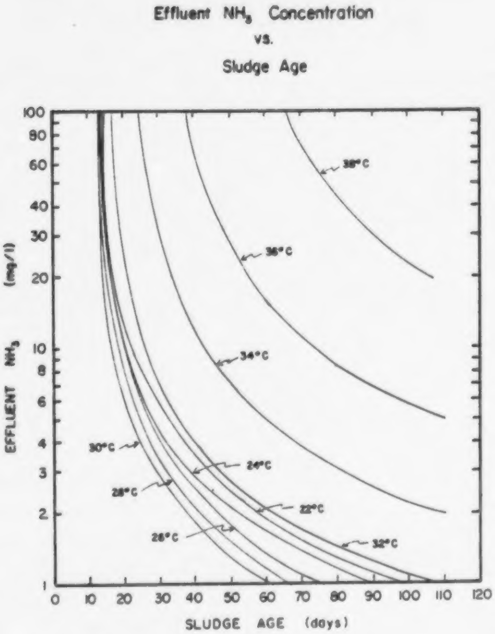


FIGURE 3

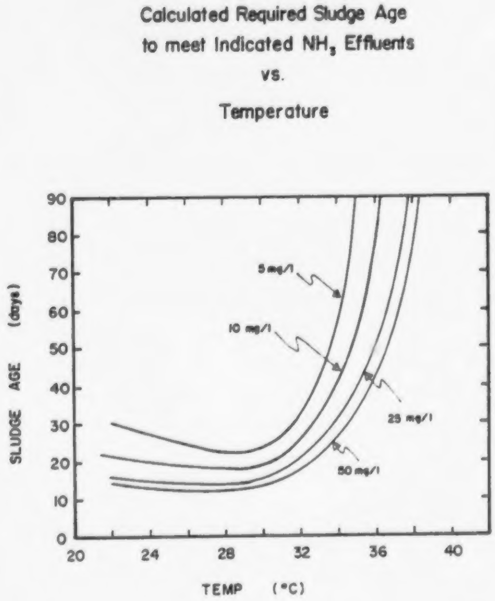


FIGURE 4

EPA Form 2350-4 (4-80)
(PREVIOUSLY CIN. EPA FORM 337)
TYPING GUIDE SHEET

$$(a)_{ob} = 0.063 \text{ lb VSS/lb } NH_3 \text{ removed} \qquad (6)$$

and for temperatures in excess of 30°C, the yield coefficient follows a relationship of:

$$(a)_{ob} = 0.1935 - 0.0043\ (T) \qquad (7)$$

It should be noted that the observed yield coefficient approaches zero when the wastewater temperature is equal to 45°C.

From the biokinetic and sludge yield parameters obtained, calculated data of sludge age and effluent quality at pH = 8 were obtained. A family of such curves for the temperature ranges considered in this study is shown on Figure 3.

In order to best interpret Figure 3, a cross plot was made of required sludge age to meet ammonia effluents as listed as a function of varying temperatures. This cross plot, shown on Figure 4 points out that stable nitrification producing an acceptable effluent quality should exist at sludge ages of about 20 days when the wastewater temperature is less than 30°C (86°F), however, instability may exist at temperatures above that level with the curve becoming very steep (indicating instability) at temperatures in excess of 33°C (91.4°F).

Experimental Results on the Influence of Organics and Cyanides on Nitrification Biokinetics

The chemicals selected for this phase of research are those which have been shown to pass through first stage bioreactors or those chemicals found in coal conversion wastewaters which are significantly resistant to microbial degradation. The substances considered are 2,3,6 and 2,4,6 trimethylphenol (TMP), 2-ethylpyridine, phenol (comparison), free cyanide, complexed cyanide, thiocyanate, and a mixture of coal tar acids derived from a local coke making facility.

As an example of some of the results to date, Figures 5 and 6 are plots of Vmax versus concentration of 2,3,6-trimethylphenol and K_m versus concentration of 2,3,6-trimethylphenol. Figure 5 shows that the critical concentration of 2,3,6-trimethylphenol is about 4.9 mg/L, with levels above that severely depressing the biokinetic parameter of the V_{max} term in accordance with the equation:

$$\text{Log } V_{max} = 0.853\text{-}1.117 \text{ Log } (2,3,6\text{-TMP}) \qquad (8)$$

Figure 6 indicates that the critical concentration for 2,3,6-trimethylphenol is about 17.2 mg/L with severe depression of the parameter K_m as trimethylphenol increases in accordance with the equation:

$$\text{Log}(K_m) = 1.839 - 1.069\ \text{Log}(2,3,6\text{-TMP}) \quad (9)$$

These relationships are combined with yield coefficient information to provide plots of effluent ammonia as a function of the independent variable sludge age in continuous culture systems.

A plot of the effect of 2,3,6-trimethylphenol level on sludge age for nitrification is outlined on Figure 7. As can be seen, even small levels of 2,3,6-trimethylphenol will dramatically effect steady state effluent ammonia levels at a given sludge age.

Similar results with "shoulders"occuring at different concentrations were found for the compounds above. A summary of shoulder values is listed on table 2.

Table 2

Values Below Which Toxicant Has No Effect On Nitrification Kinetic Parameter

Shoulder Values at pH = 8.0

Compound	Vmax (gNH_3gVSS-Day)	Km (mg NH_3/L)
* Free Cyanide	Toxic at all Values	No effect on K_m
* Phenol	Toxic at all Values	No effect on K_m
Coal tar acid mixture	1.2 mg/L as phenol	5 mg/L as phenol
2,3,6 TMP	4.9 mg/L	17.2 mg/L
2-Ethyl-pyridine	10 mg/L	42 mg/L
2,4,6 TMP	30 mg/L	50 mg/L
$Fe(CN)_6^{-3}$	80 mg/L	No effect on K_m
SCN^-	236 mg/L	No effect on K_m

* Note: Nitrification Inhibition is proportional to $(CN)^{-3}$ and $(\text{Phenol})^{0.5}$, free cyanide is far more toxic than phenol.

Figure 8 is a summary plot of required sludge age to meet a 10 mg/L NH_3 effluent versus concentration of organic inhibitors, cyanides, and thiocyanate. It should be noted that the concentration axis for thiocyanate should be multiplied by 10. Examination of Figure 8 is revealing in that it demonstrates that coal tar acids are more inhibitory

BEGIN FIRST LINE OF TEXT HERE
TYPING GUIDE SHEET
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD; BEGIN SECTIONS HERE

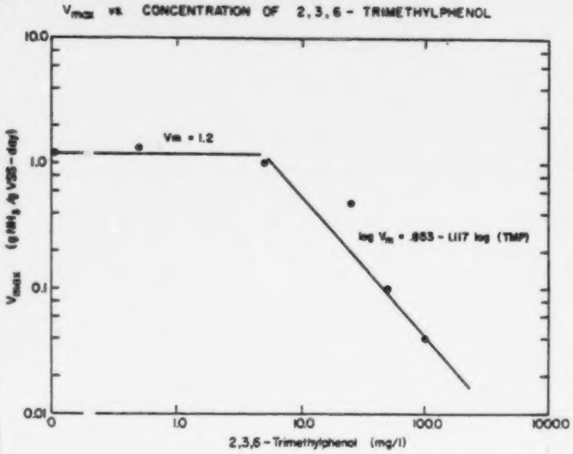


FIGURE 5

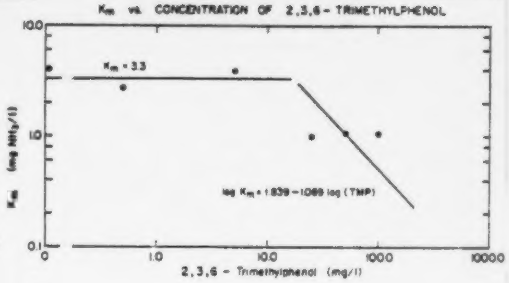


FIGURE 6

6-1/2"

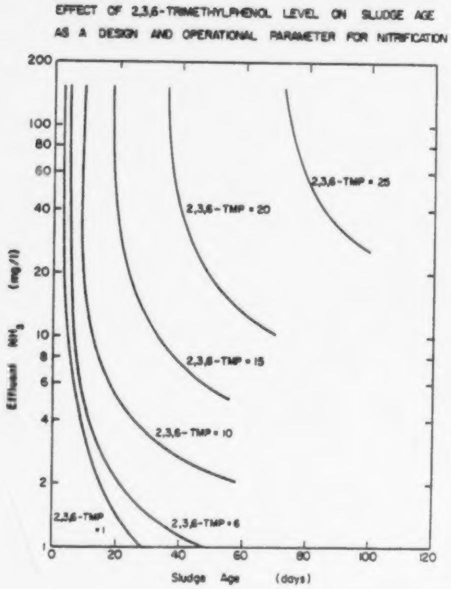


FIGURE 7

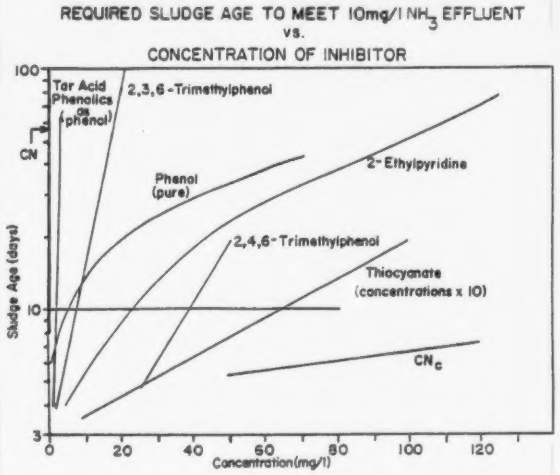


FIGURE 8

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"
PAGE NUMBER
EPA-287 (Cin.)
(4-76)

than reagent phenol, low levels of 2,3,6-trimethylphenol are far more inhibitory to nitrification then levels of 2,4,6-trimethylphenol, and free cyanide is the most toxic to nitrifiers of all the chemical species studied. Complexed cyanides and thiocyanates exhibited toxicities to nitrification only at levels far greater than that for the other species studied and may be considered "non toxic" to nitrifiers at usual levels found in coke plant effluents.

For practical purposes, by drawing a horizontal line on Figure 8 at a sludge age of 10 days, the set of intersections of this line with the curves for individual compounds provides insight into allowable levels of these substance (assuming no synergism) for nitrification. Table 3 is a listing of these levels. They should be considered as allowable levels of such trace substances in effluents so that biological nitrification may take place in a stable manner.

Table 3

Maximum Levels of Contaminents to Permit Nitrification at a 10 Day Sludge Age with Effluent NH_3 = 10 mg/L at pH = 8.0

Compound	Concentration mg/L
Free Cyanide	0.11 mg/L
Coal tar acids (as 4-AA phenol)	1.7 mg/L
Phenol	5.5 mg/L
2,3,6 TMP	7.8 mg/L
2-Ethylpyridine	22 mg/L
2,4,6 TMP	39 mg/L
$Fe(CN)_6^{-3}$	190 mg/L
SCN^-	660 mg/L

SUMMARY OF FINDINGS

Based upon laboratory data obtained, the following conclusion may be drawn concerning the effect of inhibition to biological nitrification.

1.0 Toxic inhibition to biological nitrification decreased in the order of free cyanide, tar acid phenolics, phenol, 2,3,6-trimethylphenol, 2-ethylpyridine, 2,4,6-trimethylphenol, complexed cyanide and thiocyanate.

2.0 All substances, except free cyanide and phenol, appeared to follow a "shoulder effect" whereby low levels of inhibitor had no influence on the rates of biological nitrification while higher levels had profound effects. The absence of the shoulder effect is an indication that low levels of free cyanide should be avoided for stable operation of biological nitrification processes.

3.0 Calculations based on laboratory data are provided to show maximum levels of contaminents that will still permit stable nitrification at a 10 day sludge age at pH = 8 and effluent ammonia levels of 10 mg/L.

4.0 Upper temperature limits for stable optimum nitrification is 30°C.

5.0 Free (or unionized) ammonia is inhibitory at levels of 10 mg/L or more. Free ammonia is mainly a function of wastewater total ammonia, pH, and temperature.

References

(1) Neufeld, R. D. , Hill, A. J., Adekoya, D.O. "Phenol and Free Ammonia Inhibition to Nitrosomonas Activity" Water Research, Vol 14, #12 pp1695 - 1703 (Dec. 1980)

(2) Neufeld, R. D., Rieder, C. B., Greenfield, J. H. "Influence of Elevated Temperatures on Nitrification Biokinetics as Applied to Steel Industry Wastewaters" report to AISI, project 78 - 395 (August 1, 1980)

(3) Neufeld, R. D., Greenfield, J. H. "Influence of Free and Complexed Cyanides an Nitrification as Applied to Steel Industry Wastewaters" report to AISI under project 78 - 395 (August 1, 1981.)

(4) Neufeld, R. D., Greenfield, J. H. "Factors Influencing Nitrification Biokinetics as Applied to meeting BAT Requirements for the Iron and Steel Industry" Final report to AISI under project 78 - 395 (August 1, 1982)

Acknowledgement: This project was supported by the Research Committee of the American Iron and Steel Institute, and by the Industrial Environmental Research Laboratory of the U.S. Environmental Protection Agency.

Although the research described in this paper has been funded wholly or in part by the U.S. Environmental Protection Agency, it has not been subjected to Agency review and therefore does not necessarily reflect the views of the Agency and no official endorsement should be inferred.

EFFECTIVE OPERATION AND MAINTENANCE PRACTICES FOR WASTEWATER TREATMENT SYSTEMS IN THE IRON AND STEEL INDUSTRY

by: William F. Kemner - Assistant Director, Engineering Division
Richard T. Price - Environmental Engineer

PEDCo Environmental, Inc.
11499 Chester Road
Cincinnati, Ohio 45246

ABSTRACT

This paper presents some of the results of a current study of operating and maintenance (O&M) practices for wastewater treatment systems in the iron and steel industry. The purpose of the study is to document effective O&M practices and how their application might affect permit parameters and operational upsets. The ultimate goal of the study, which is funded by the Industrial Environmental Research Laboratory (Research Triangle Park, North Carolina) of the Environmental Protection Agency, is to produce an O&M report that will assist both agency inspectors and plant personnel.

The wastewater generating processes selected for study were byproduct cokemaking, ironmaking (blast furnaces), steelmaking (basic oxygen furnaces), hot forming, and acid pickling. Selections were based on pollutant loadings, system complexity, control costs, and commonality among the majority of integrated steel mills.

Information was gathered from several sources: a literature search for wastewater-related O&M practices in the iron and steel industry, discussions with state and regional agency personnel to identify major areas of concern and effective O&M practices, review of agency files, discussions with wastewater treatment equipment vendors, and discussions with industry representatives.

Various steel mills were visited, and treatment plant operators and environmental staff members were interviewed. The information produced by these visits includes typically encountered problems and their solutions, troubleshooting efforts, extent of operator training, efforts to minimize the effect of operational upsets, and preventive maintenance practices.

The study will culminate in the preparation of a report intended to provide a better understanding of wastewater problems in the iron and steel industry, to help agency inspectors to be more effective in evaluating the effect of O&M practices on wastewater treatment performance, and to provide information that will assist plant personnel in practical and cost-effective fine-tuning of their systems.

INTRODUCTION

Because the depressed production levels in the iron and steel industry made it more difficult than expected to schedule plant visits, the study is not yet complete. Therefore, this paper describes some of the findings to date and is limited to discussion of effective O&M management practices, some problems with effective O&M practices for example treatment system components, and sampling and self-monitoring data.

In general, the authors were favorably impressed with the operation and maintenance of the 12 treatment systems examined to date. No system was without its problems (varying in nature and severity) but none of the systems seemed inadequate.

Most of the effective O&M practices described in this paper are examples of actual practices observed at several steel mills. The information was collected by interviewing treatment system operators and maintenance personnel. The plant's environmental department made provisions for us to visit the plants and coordinated the visits with various O&M supervisors and operators. Every plant was most cooperative.

EFFECTIVE OPERATION AND MAINTENANCE MANAGEMENT PRACTICES - TREATMENT SYSTEM GENERAL

Effective O&M practices at a wastewater treatment system are those that can keep the system operating at its optimum (hopefully design) performance with minimal downtime.

It is management's responsibility to initiate and maintain an O&M plan. Although most of the following O&M practices (i.e., communication, operator training, staffing, recordkeeping, preventive maintenance, and treatment system auditing/evaluation) are probably implemented in some degree at all plants, their effectiveness depends on the degree to which they are practiced, how carefully they are practiced, and whether they are fine-tuned periodically (if necessary) to achieve optimum effectiveness.

Our plant visits have shown that the management organization for water pollution control has much to do with successful communications and with obtaining the cooperation necessary to solve problems expeditiously. Generally, the management structure at the plants visited was as follows:

- The utilities (power and fuels) department is responsible for operating the wastewater treatment systems.
- The process department, which is responsible for the steel mill process operations, assumes at least part of the responsibility for delivering wastewater to the treatment systems.
- The environmental department keeps all pertinent personnel informed of current and expected water regulations that will have an impact on the plant. This department serves as a go-between for the plant's pollution control section of the utilities department and the regulatory agencies and is responsible for all correspondence with the agencies.

Table 1 shows a breakdown of which departments actually operate or maintain the process wastewater treatment systems at the plants visited to date.

TABLE 1. DEPARTMENTS THAT OPERATE AND MAINTAIN WASTEWATER TREATMENT SYSTEMS AT VISITED PLANTS

	Utilities department		Process department		Environmental department	
	O	M	O	M	O	M
Blast furnace	2	1		1		
Coke plant:						
Biological treatment	1	1	1	1		
Ammonia still			2	2		
Hot strip mill:						
Scale pits	1		3	4		
Clarification/sedimentation	4	1		3		
BOF	3	1		2		
	11	4	6	13	0	0

Observation of the workings of these departments (particularly process and utilities) indicates that pollution control needs are met most effectively when the utilities department has both a maintenance staff and an operating staff. It also appears to be advantageous for some equipment that has typically been operated by the process department (e.g., scale pits) to be operated instead by the utilities department, or that a strong spirit of cooperation exist between process and utilities departments. This is especially important when the operation of the control equipment is greatly affected by the operation of the process equipment (e.g., coke byproduct plants). For example, an effective situation at one coke plant involves a byproducts engineer and a process supervisor (responsible for the biological treatment system) working hand-in-hand. This arrangement is effective because both are in the same department and have a common goal--the optimum performance of the byproducts plant/biological treatment system.

When a utilities department does not have its own maintenance staff and has to rely on maintenance help from production departments, there is competition for maintenance resources. If production needs are greater, chances are good that the pollution control department will have to wait until maintenance personnel are available.

An alternative to the utilities department having its own maintenance staff is to have operators perform some of the day-to-day maintenance, such as routine equipment oiling/lubrication and minor pump repairs. This approach seemed to work at one plant. With the burden of routine maintenance taken off the maintenance department, they are able to make time for larger repair jobs requested by the utilities department.

COMMUNICATION

Proper communication is essential to effective O&M. Figure 1 illustrates effective and ineffective communication structures, both of which were noted during the plant visits. In the effective system, all personnel connected in some way to the generation of wastewater and its treatment have good communication lines. In the plants visisted, most of the treatment systems were operated by the utilities department, so the utilities supervisor is a key person in making the communication system work.

In the example shown, strong two-way communication lines are required between the utilities supervisor and his operators and maintenance personnel. Frequent contact must exist between the supervisor and operators to keep the supervisor posted on the day-to-day operation of the treatment systems. We noted direct communication between operators and supervisors (face to face or by telephone) anywhere from once an hour to once a shift. Indirect communication (use of logs, records, computer terminals) occurred at about the same frequency.

Effective communication allows the utilities supervisor to stay on top of things and to make decisions more quickly when a problem arises. Frequent communication seems to make the operators realize the importance of their jobs. Only through effective communication ties between operators, supervisor, and maintenance personnel can problems be brought to the attention of the necessary parties. These open communication lines also allow discussion and consideration of alternate solutions to problems.

The utilities supervisor also must maintain frequent and effective communication with the lab to be kept abreast of analytical results. These results are indicators of treatment system performance that can be communicated up or down the management ladder as required.

Good communication lines also should be established between the utilities supervisor and the environmental supervisor to keep the latter informed regarding how well the plant's treatment systems are operating and whether problems have arisen that have caused or could cause outfall excursions. The environmental supervisor must also have an open line to the lab supervisor and to the utilities supervisor. The latter needs to know how treatment system problems can affect an outfall, how the regulatory agencies may react to certain situations, and what new regulatory developments are occurring that will affect him.

Another important communication line is that between the utilities supervisor (or his operators) and the process supervisor (or his operators) so that process problems or significant changes affecting water quality and quantity can be relayed to the treatment system operating department as quickly as possible. Intermediate action often can be taken at the treatment plant to reduce the possibility of a treatment system upset (e.g., diversion of spilled material or slug to a holding basin).

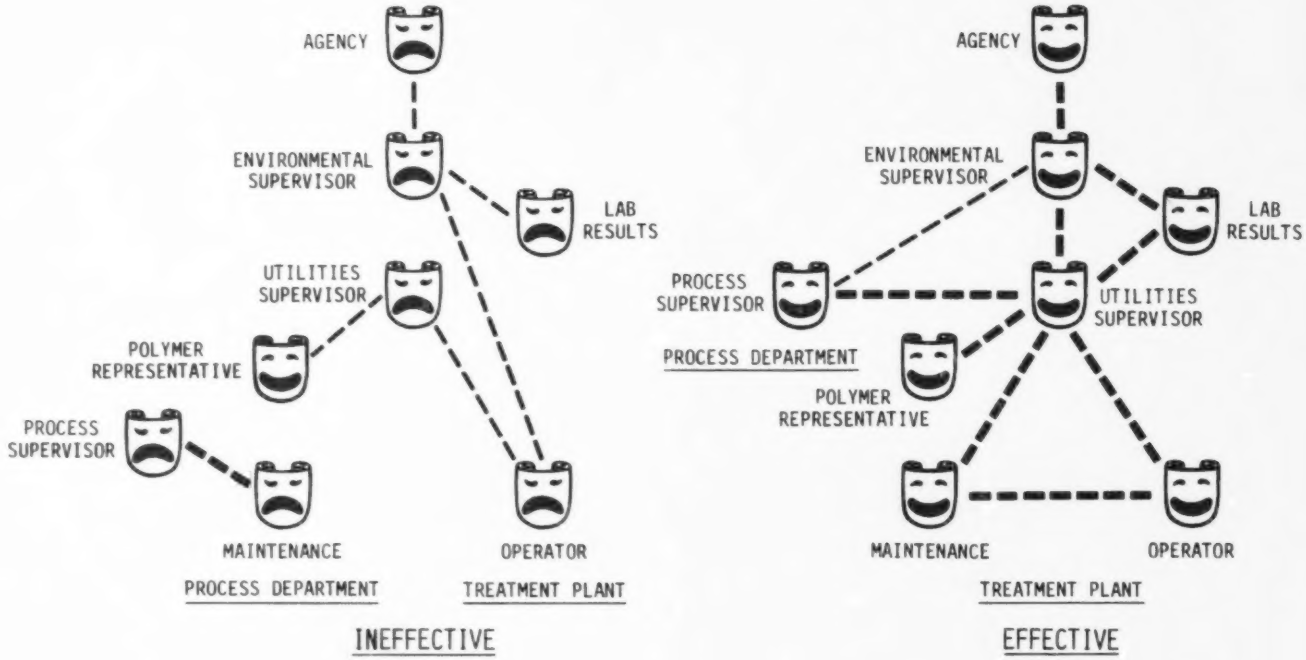

AGENCY
ENVIRONMENTAL SUPERVISOR
LAB RESULTS
UTILITIES SUPERVISOR
POLYMER REPRESENTATIVE
PROCESS SUPERVISOR
MAINTENANCE
OPERATOR
PROCESS DEPARTMENT
TREATMENT PLANT
INEFFECTIVE
AGENCY
ENVIRONMENTAL SUPERVISOR
LAB RESULTS
PROCESS SUPERVISOR
UTILITIES SUPERVISOR
PROCESS DEPARTMENT
POLYMER REPRESENTATIVE
MAINTENANCE
OPERATOR
TREATMENT PLANT
EFFECTIVE

Figure 1. O&M communication structure.

OPERATOR TRAINING

Proper and adequate training of operators is very important for effective operation of a wastewater treatment system. The operators need to know

- How their systems operate and how to handle routine daily problems.
- What pollutants are being removed and where they are destined to go (sinter plant, landfill, recycle).
- Where the treated water goes.
- How the steel mill depends on them (directly for return of needed water, or indirectly from potential regulatory action).
- What daily routines must be followed.
- What to do during emergency situations.

An effective operational practice at one plant was a personalized examination prepared by the operating supervisor and given to the operators. Although this test was not required by the plant or given by other operating supervisors within the plant, the supervisor we interviewed was convinced that it was necessary for his own assurance that the operators knew how to handle essentially all conceivable situations. It should be mentioned that requiring operators to take exams is not popular with the union; however, there are ways to test operators within contract guidelines.

After talking to various operators, we were convinced that those who were present at system startup and had the benefit of receiving thorough training by the equipment manufacturers were good, well-trained operators. Subsequent generations of operators seemed to have received less formalized training or practically none at all.

An effective operational practice, therefore, is to ensure that new operators receive the same level of training as the "startup" operators. If this is not possible, a practice found to be effective is to have a process supervisor (for the process whose wastewater is going to treatment) show the operators the source(s) of wastewater and explain the process variations that can affect the flow rate and the quality of the wastewater. Also, a representative of the plant's environmental department should explain the importance of effective operation and the role of the environmental department.

Another useful aid that some operators had developed involved simplified schematics of their equipment and/or overall treatment scheme. These diagrams were usually much less complex than those in the O&M manuals provided by the design engineers.

LOGS/RECORDKEEPING

Good logs and recordkeeping are effective O&M tools. Our plant visits indicated that current practice varies from maintaining essentially no records to recording numerous parameters every two hours. It would be difficult, if not impossible, to recommend a standard record sheet and logging frequency for a particular treatment system because operations vary greatly from plant to plant and system to system. The variables depend on management philosophy, who the logs benefit, the necessity of the recorded data, the degree of instrumentation for a given system, etc.

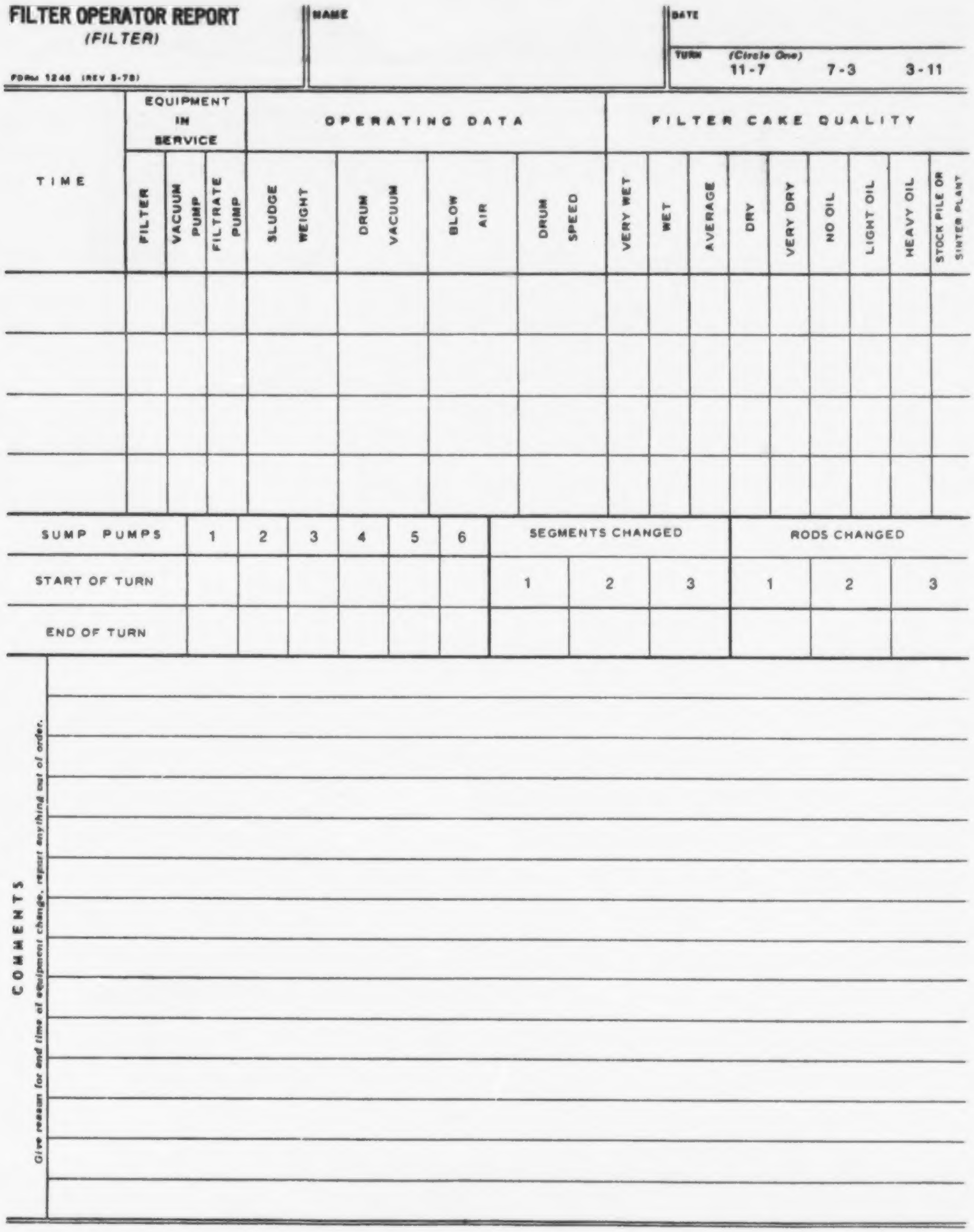
Nevertheless, it can be said that at those plants observed to have well-operated systems the operators made a practice of logging in key operating parameters on a periodic basis. In addition, the operating supervisors at these plants review the logs for abnormal conditions and initiate followup action. In other words, the logs were not taken to lie idle. Examples of log sheets (blanks) that were used effectively at two plants are shown in Figures 2 and 3.

Collected data also are useful for plotting certain parameters versus time to show trends. This can be very effective in showing how process changes affect water quality of the influent to a control system, how control system changes or a new polymer affect outlet water quality, or how a new equipment installation affects outfall water quality. It is frustrating to search through reams of logs and records (Figure 4) to try to understand what effect a change had on something.

The use of records to plot trends did not appear to be a common practice at any of the plants visited (even though the systems were well operated for the most part); however, such plots can be very effective in illustrating a point to process, utilities, and environmental supervisors and to regulatory agency personnel.

A process supervisor at one plant was able to use data that he had plotted to convince plant management there would be fewer permit excursions and less process equipment downtime if a preventive maintenance (PM) schedule were followed. Figure 5 shows a section of the plotted data. For each peak (excursion above control limit), the process supervisor reviewed maintenance work orders and was able to write down the cause of the excursion. In doing this over an approximate two-year period, he saw a trend in equipment breakdowns or pluggages vs. the excursions. This information enabled him to prepare a preventive maintenance schedule (Figure 6), which was implemented by management and has proved to be very effective.

Most plants have log sheets they have developed for their systems. Although none was seen in the plants visited, another effective tool that the authors have seen in use outside the iron and steel industry is the inclusion of a control chart with maximum and/or minimum parameter values shown on the log sheet so the operator can circle exceeded values. This forces the operator to know what the acceptable operating range is; it also provides his supervisor a quick visual aid for ascertaining where deviations from the normal range have occurred. Taking this further, a deviation or exception report can be prepared periodically (e.g., weekly or monthly) to show the supervisor how the system has been operating.



FILTER OPERATOR REPORT
(FILTER)

FORM 1246 (REV 5-78)

NAME

DATE

TURN *(Circle One)* 11-7 7-3 3-11

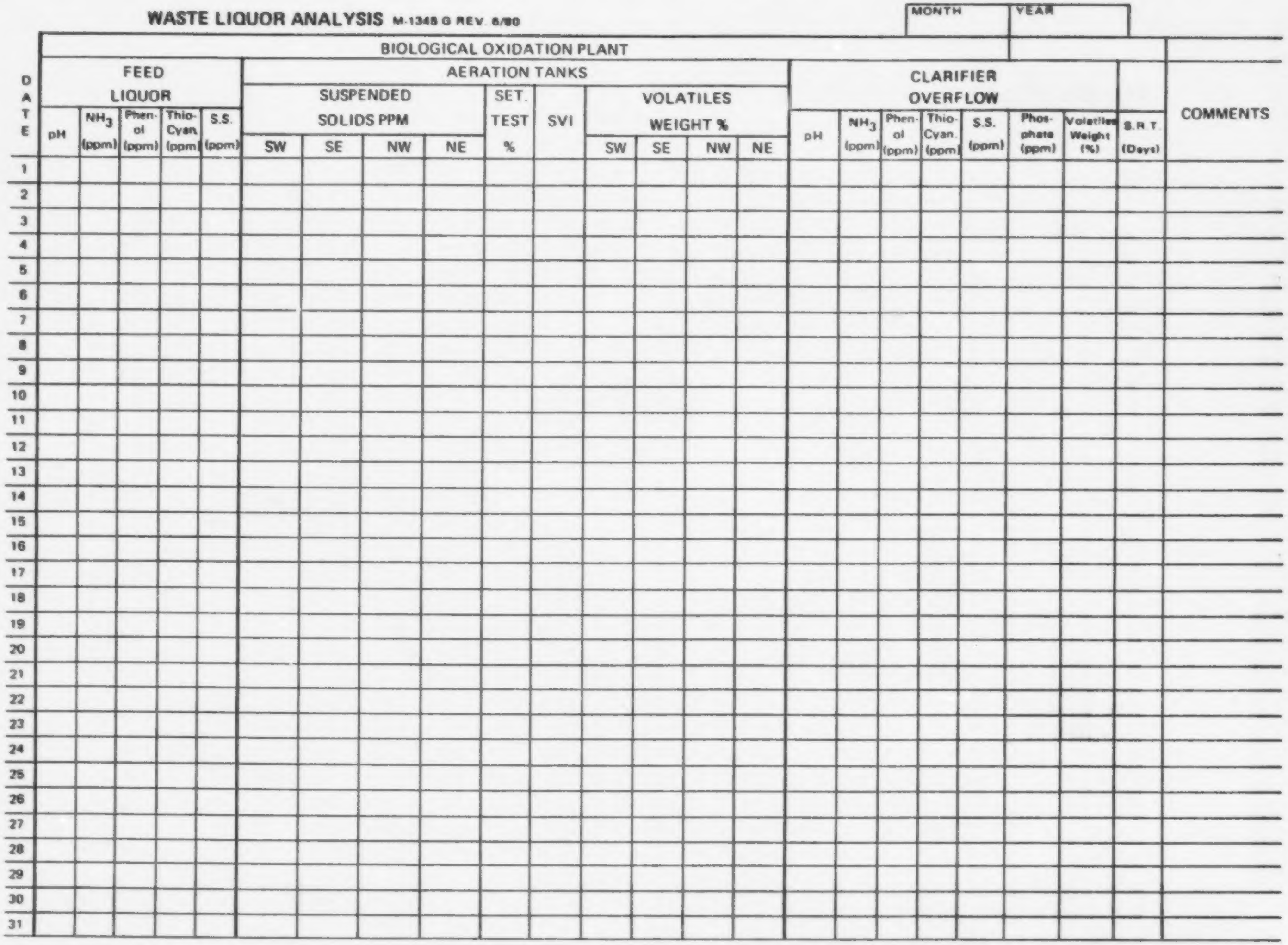
	EQUIPMENT IN SERVICE			OPERATING DATA				FILTER CAKE QUALITY								
TIME	FILTER	VACUUM PUMP	FILTRATE PUMP	SLUDGE WEIGHT	DRUM VACUUM	BLOW AIR	DRUM SPEED	VERY WET	WET	AVERAGE	DRY	VERY DRY	NO OIL	LIGHT OIL	HEAVY OIL	STOCK PILE OR SINTER PLANT

SUMP PUMPS	1	2	3	4	5	6	SEGMENTS CHANGED			RODS CHANGED		
START OF TURN							1	2	3	1	2	3
END OF TURN												

COMMENTS

Give reason for and time of equipment change, report anything out of order.

Figure 2. Example of log sheet - vacuum filter.



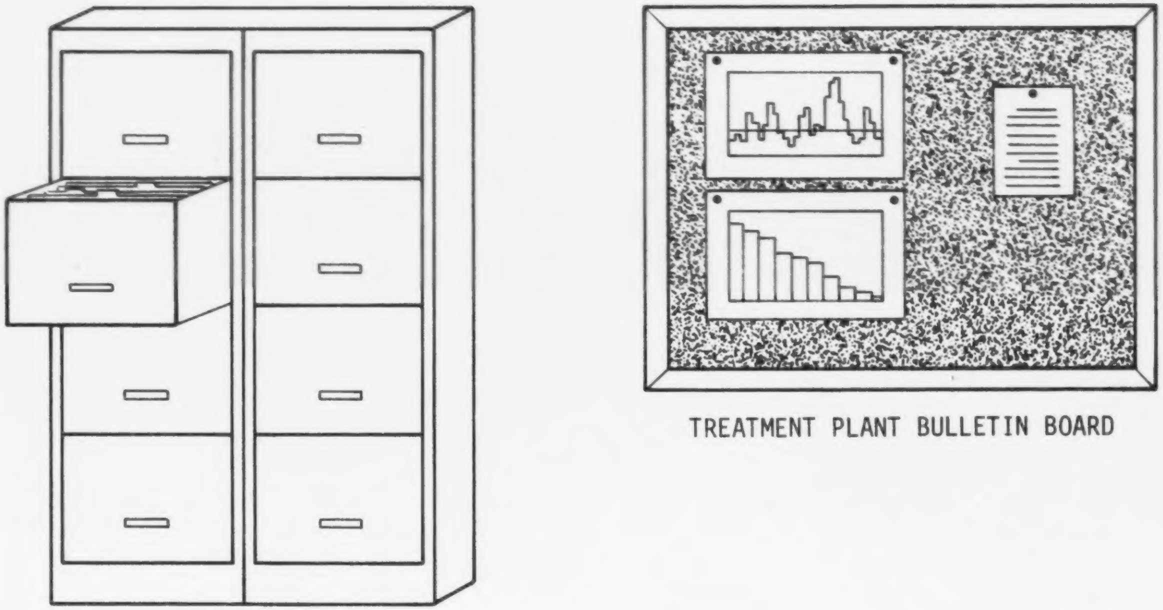
WASTE LIQUOR ANALYSIS M-1348 G REV. 8/80

MONTH

YEAR

	BIOLOGICAL OXIDATION PLANT																							
DATE	FEED LIQUOR					AERATION TANKS										CLARIFIER OVERFLOW								COMMENTS
						SUSPENDED SOLIDS PPM				SET. TEST %	SVI	VOLATILES WEIGHT %												
	pH	NH_3 (ppm)	Phenol (ppm)	Thio-Cyan (ppm)	S.S. (ppm)	SW	SE	NW	NE			SW	SE	NW	NE	pH	NH_3 (ppm)	Phenol (ppm)	Thio-Cyan. (ppm)	S.S. (ppm)	Phosphate (ppm)	Volatiles Weight (%)	S.R.T. (Days)	
1																								
2																								
3																								
4																								
5																								
6																								
7																								
8																								
9																								
10																								
11																								
12																								
13																								
14																								
15																								
16																								
17																								
18																								
19																								
20																								
21																								
22																								
23																								
24																								
25																								
26																								
27																								
28																								
29																								
30																								
31																								

Figure 3. Example log sheet - biological treatment system.


TREATMENT PLANT BULLETIN BOARD

WRONG

RIGHT

Figure 4. Effective use of records.

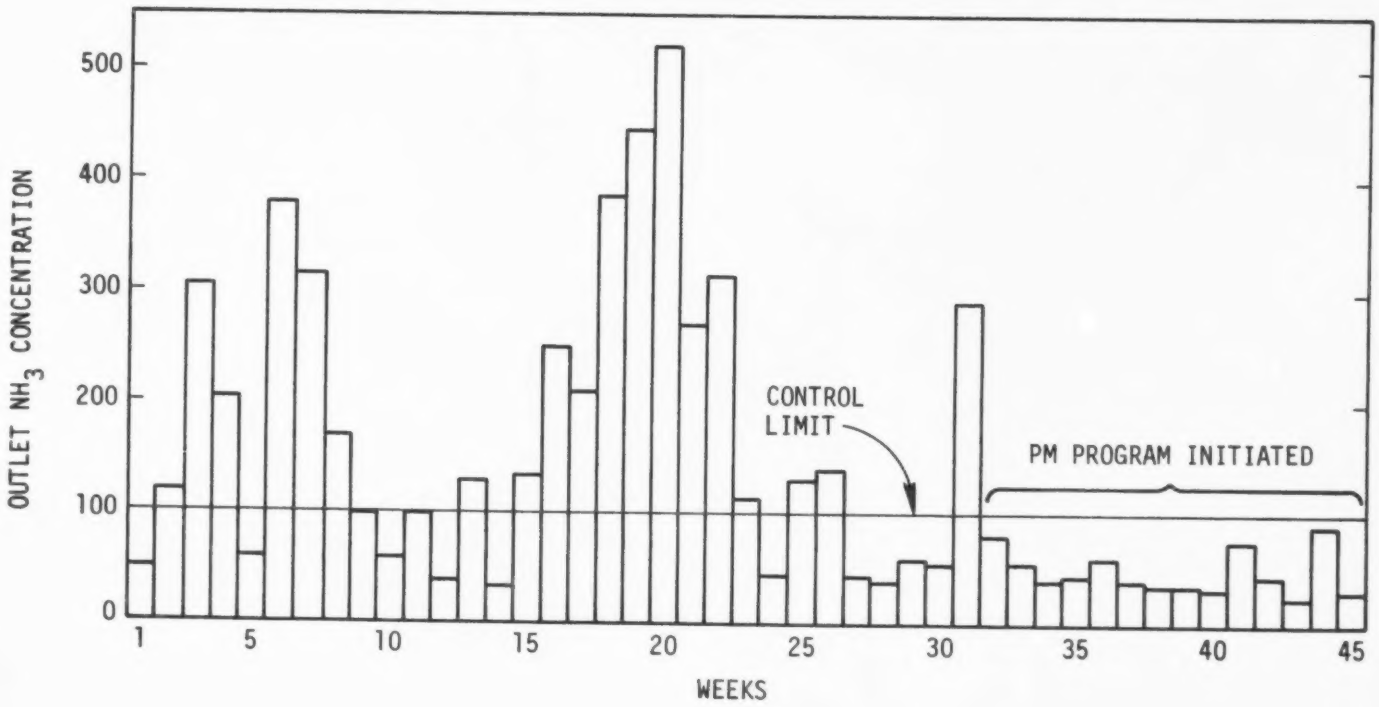


Figure 5. Ammonia still performance.

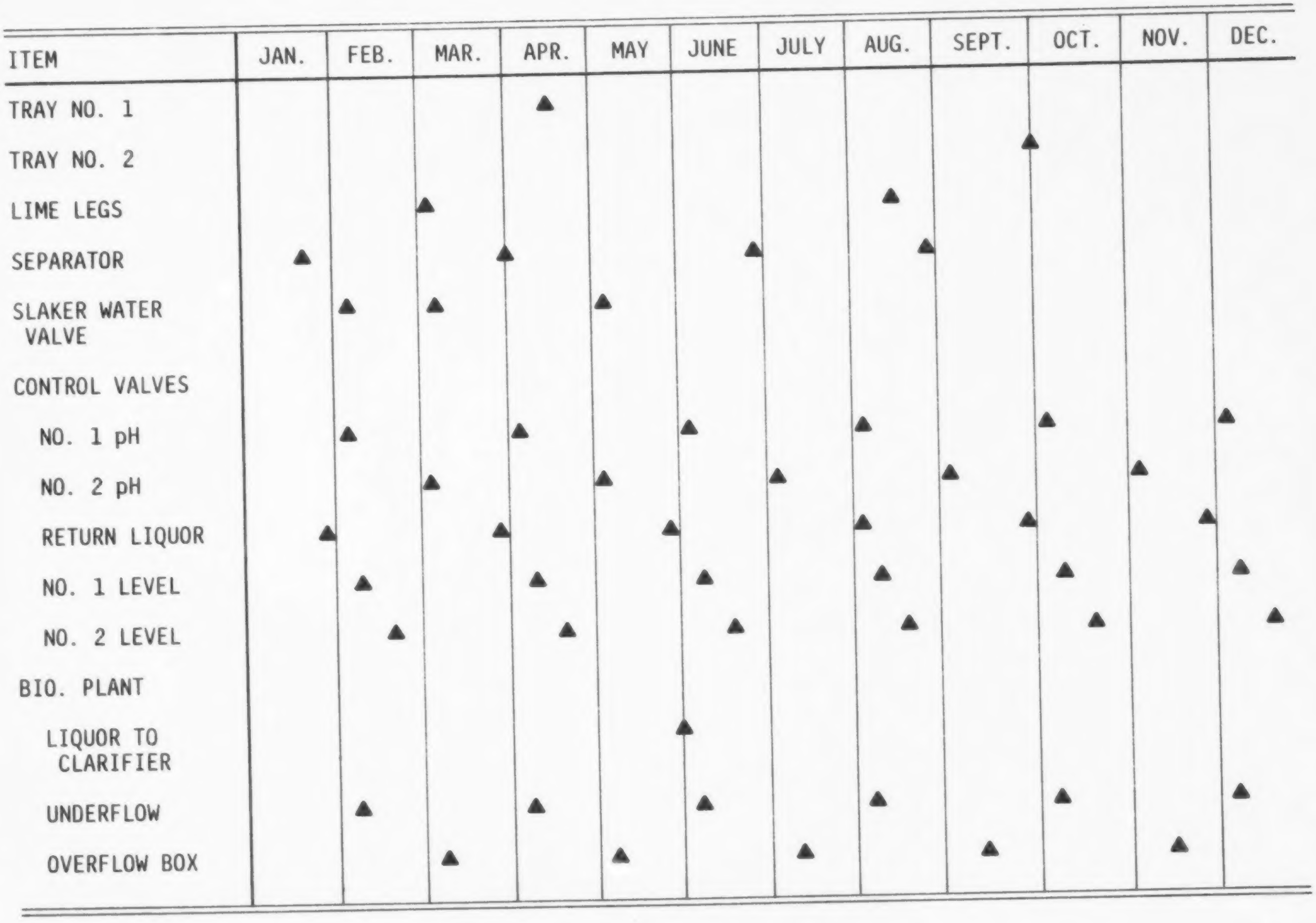


Figure 6. Example of annual preventive maintenance schedule.

STAFFING

Obviously, proper operation of a treatment system requires a sufficient number of operators (and assistants and helpers) with clearly defined job functions.

The systems at all the plants visited under this study were well staffed. In fact, a few of the systems could have been properly operated with one less operator. At one plant, however, an efficient operator had to devote all of his time to manually controlling the treatment system (filtration plant). Had this operator been responsible for areas other than the filtration plant, the filters would have plugged and the system would have been damaged and/or solids in the filter effluent would have increased dramatically.

TREATMENT SYSTEM AUDITING

Results of this study indicate that most plants have proceeded from permit negotiation to system design to routine operation without ever having stepped back to take an overview of their situation. As in any ongoing operation, the individuals involved are too busy with day-to-day concerns to take time to assess their overall system. One person is aware of some of the problems and another person knows of other problems, but they seldom have the opportunity to exchange notes. A formal O&M audit had not been performed in any of the plants visited, and none was planned. One company that we have not visited is currently performing such a study on their own, however.

We would suggest that audits or self-evaluation programs be implemented periodically (e.g., annually) by a plant team or an outside consultant. When the evaluations reveal less-than-optimum conditions, corrective action should be taken with followup to ensure that approved suggestions have been carried out.

EXAMPLES OF PROBLEMS AND EFFECTIVE O&M PRACTICES WITH TREATMENT SYSTEM COMPONENTS

SCALE PITS

Although scale pits are one of the least sophisticated and low-profile treatment technologies, they play a key role in the performance of hot strip mill (HSM) treatment plants. The scale pit performs three functions: 1) initial removal of floating oil and scum, 2) equalization of flow and temperature, and 3) sedimentation of heavy solids.

In every plant, excessive oil from the mill is a common occurrence. The oil skimming arrangements often have difficulty keeping up. Even after the skimming, oil containment and handling operations are major activities. Apparently, the cost of oils, greases, and hydraulic fluids for the mills do not yet justify the cost of spill and leakage control at the source. Treatment plant operators are resigned to the oil problem and do the best they can to cope with it. Oil carryover into deep-bed filters, for example, decreases filter efficiency, increases backwash frequency, and inhibits good cake formation in the vacuum filter.

Equalization is an important function because the demand for water at hot strip mills is highly variable, changing dramatically each time a slab is rolled. Scale pit capacity must be large enough to dampen these variations while still holding as level as possible. If the level gets too high, the pit may overflow to a blowdown; if the level is too low, the oil skimmers may be less effective (depending on design) and settling time is decreased.

The solids removal efficiency of a scale pit is dependent on the effective retention time. If the pit fills up with scale, or if level is maintained too low, removal efficiency decreases and the solids removal burden on downstream treatment modules increases. Several plants reported increased solids loadings out of the pit during scale removal activities. It is advisable to clean the pits during downtimes or have divided pits. Some plants use flight conveyors, but high maintenance caused one plant to discontinue this approach in favor of clam shelling.

Adequate attention to scale pit operation is advisable to decrease the burden on the remainder of the treatment system. In general, problems in the front end of a treatment system tend to be magnified and become progressively more difficult to rectify as they proceed through the system.

DEEP-BED FILTERS

On first consideration, deep-bed filters on hot strip mills appear to be relatively simple and reliable. One such filtering system was observed for about a day, however, and 22 O&M related problems were observed, as summarized in Table 2. In fairness to the particular plant, the filter effluent was crystal clear and was meeting permit parameters. The misleading part of this example showing 22 problems and few if no permit excursions, however, was the operator attention required. The operator was constantly busy observing changing flow conditions and pressure drops across the filters, and manually controlling flows, backwashing cycles (scrub, high-rate rinse), valves, and pumps. He also had to constantly monitor scale pit level. In this system, the absence of a hard-working, above-average operator would have been disastrous.

CLARIFIERS

One of the most common maintenance problems with a clarifier is a plugged sludge line as a result of such items as hardhats, tools, and general trash. When these items sink, a rake moves them into the sump at the bottom of the clarifier and they plug the sludge line. Also, sludge that becomes too dense will cause pluggage problems. The best way to minimize this problem is to design the sludge lines so they can be cleaned easily. Some facilities provide a tunnel around the sludge line so the maintenance man will have access to the entire length of the line. Another technique is to install two sludge lines so that if one becomes plugged, the other can be used. At some installations a wire mesh or some other barrier has been installed across the top or on the sides of the clarifier to prevent large objects from falling in. Anytime the clarifier is drained for maintenance, the sludge sump should be inspected thoroughly before the unit is put back on stream to ensure that no miscellaneous items (e.g., nuts, bolts) were left there by maintenance personnel.

TABLE 2. PROBLEMS OBSERVED ON HSM DEEP-BED FILTRATION

1. Flow meters inoperative
2. One of 12 filters out of service over several months
3. Oil skimmers in scale pit unable to handle all the oil
4. Vacuum filter system inoperative (and no installed spare)
5. Frequent backwashing due to sludge returned to pit
6. Automatic backwash not functional--manual backwash required
7. Little communication between HSM and treatment plant
8. No log book maintained
9. Samples taken once every two weeks
10. Maintenance needs communicated verbally
11. No maintenance logs
12. Separate electrical and mechanical maintenance
13. System highly operator-dependent
14. Excessive oil from HSM into scale pit
15. No inspection of filters conducted
16. Possible for collected oil to overflow back into pit
17. Pit level control dependent on operator attention
18. No preventive maintenance program
19. More frequent plugging of filters closest to inlet--distribution problem
20. Good cake formation hindered by oil in vacuum filter
21. No spare parts inventory available to maintenance--kept by engineering
22. Lack of adequate communication; responsibilities divided among operations, utilities, engineering, and environmental departments

Debris in the clarifier can also jam the rake. Rake failure also can be caused by mechanical problems such as a section of the rake falling off or the rake getting out of balance and scraping the bottom of the clarifier. If the sludge is not pumped away rapidly enough or its composition changes so that it becomes denser, it can create enough resistance to stop the rake. When the sludge is not removed, it builds up in the clarifier and eventually overflows the weir, creating a dirty effluent. Also, the vacuum filter may not operate well on dilute sludge.

Most clarifier rake drives are equipped with a torque meter set to sound an alarm at a certain level (e.g., at 75 percent of full torque) and will automatically shut down at a higher level to prevent the motor from burning out. One facility installed a microswitch that recorded each time the rake made a full revolution. This switch was wired to a timer, and if the rotation time of the rake became excessive, it would automatically stop the rake drive and sound an alarm. Another safety factor that is sometimes built in is an automatic rake-lifting device. This lifting action will sometimes free the rake from what was restricting its motion.

The condition of the clarifier feed can be checked with a simple settling test. The test performed by most of the plants visited consists of putting a sample of clarifier feed in a graduated cyclinder or Imhoff cone and noting the sludge level after a certain time. At two plants, the clarifier feed was considered to be satisfactory if the sludge level was between 25 and 30 ml. Although this test does not give an absolute measure of settling rate, it is a good check for relative settling rates and will detect an upset in the system. If a plant adopts such a test and takes this measure every few hours, a problem in the clarifier feed can sometimes be detected before it leads to a major upset.

The turbidity in the clarifier overflow should be checked frequently. None of the facilities we visited had what they considered to be a satisfactory continuous turbidity measuring device on the clarifier overflow. None of the instruments tried was reliable. In the absence of such an instrument, the operator should manually pull a sample of clarifier overflow and do a lab check on the turbidity. If a satisfactory turbidity meter is found, such manual checks should still be made occasionally to ensure that the instrument is operating properly.

A visual inspection of the clarifier will tell the operator if the sludge level is getting near the overflow weir. The operator should also check to be sure the effluent flow over the clarifier perimeter weir is uniform. If the flow over one portion of the weir is greater than over another portion, the increased velocities can create turbulence.

If all the factors mentioned above have checked out and the clarifier effluent is dirty, the clarifier may be operating at too high a feed rate. The actual feed rate should be checked against the design feed rate. If the feed rate and the area of the clarifier are known, the liquid rise rate can be calculated. If the feed rate is excessive, there may not be a simple solution. This condition usually results from the treatment plant having been underdesigned initially or the occurrence of plant expansions after the treatment plant was designed. Usually the only solution to this problem is to add another clarifier. If the treatment plant uses multiple clarifiers, it may be that the flow is not being diverted equally to the clarifiers. In this case, the reason for the uneven flow must be found and corrected.

A more subtle reason for poor clarifier performance may be a change in the feed composition or a problem with the polymer being used. It is apparent that the use of polymers is both common and effective in many steel wastewater treatment systems. Most plants leave much of the responsibility for the polymer program (mixing and addition systems) up to the chemical supplier. Whereas this practice appears to be satisfactory in most cases, periodic formal review of the program is recommended, both to control chemical costs and to review the effectivenes. The flocculation and settling performance of the clarifier feed can be checked by using standard jar test apparatus. These test parameters are approximate, and the test is most useful if a benchmark test is available that was run during a period of good clarifier operation. A bad polymer can be found by using this test to compare the polymer being used in the clarifier with a fresh batch of polymer made up in the lab. After the settling rate has been determined, some of the liquid can be siphoned from the jar for a suspended solids analysis. The suspended solids level should approximate the clarifier overflow, although again this is most useful as a comparative test against the benchmark test.

If the solids being settled in the clarifier come from a scrubber such as those used for basic oxygen furnaces, the problem may be an increased level of fines in the water due to the way the furnace is operating. These fines, which are scrubbed out and sent to the clarifiers, make settling more difficult. Settling can sometimes be improved by switching polymers.

Most clarifiers in BOF treatment systems are preceded by a (primary) separator (e.g., cyclone). If the cyclone malfunctions or is bypassed, it will increase the solids loading on the clarifier.

AMMONIA STILLS/BIOLOGICAL TREATMENT

Some of the effective O&M practices observed at two plants include the following:

- Caustic is now used in the ammonia stills at one plant rather than lime. The still used to plug up frequently, creating fluctuations in the ammonia concentration of the wastewater to the treatment system. With the use of caustic, problems with the ammonia stills are minor.

- The lime plugging problems at the other plant were minimized by improving the lime slaking operation. (The plant experimented with caustic and found it to be very effective for good still performance with good ammonia reduction; however, cost of using caustic vs. lime was several times greater, so the plant decided to use lime.) They try to maintain an optimum lime slaking temperature of approximately 95°C, and have a lime crush size of minus 1/4 inch (75-80% through screen). They also try to maintain a purchased lime quality of $\geq$95% calcium oxide. The lime slurry is continuously cycled from the lime slaker tank to the ammonia still. A bleed line from the loop to the still supplies the lime to the stills as needed.

- Large tanks preceding the bio-oxidation basins serve as equalization tanks at one plant and as surge tanks at the other plant. Lime carryover from the still settles in the surge tank and is periodically pumped out with a vacuum truck. The level in the equalization tank is recorded continuously on a strip chart.

- At both plants, conditions at the bio-oxidation basin are monitored frequently to observe any changes that could cause system upsets. Phenol, ammonia, pH, thiocyanate, and total suspended solids are sampled and analyzed at least daily. Both plants maintain their basin temperatures between 26° and 30°C, not allowing it to vary more than 2° or 3°C during any season. One plant logs aeration basin temperatures every two hours throughout each day; the other plant measures temperature continuously. Temperatures are adjusted with coolers or live steam as required. Influent flow is also measured and recorded.

- Phosphoric acid is used as a nutrient in the aeration basins. The amount used is adjusted to give a desired phosphate residual. (The plants reported 1 to 10 ppm.)

- Both plants add service water in amounts required at the basin influents to equalize the inlet concentrations to get maximum performance from the microorganisms.

- Normal foaming that occurs in the biological treatment systems is controlled at one plant by adding an antifoam agent at each aerator. Water sprays are used to break up foam at the center well of the clarifier (following the bug pond) at the other plant.

- An amp meter is used effectively at one plant to indicate clarifier rake amperage. It is normally 25 to 30 amps and is checked on a log sheet every two hours. Deviations from this range are cause for quick action.

- Sludge recycle rates are monitored closely and solids settling tests (with Imhoff cones) are performed every two to four hours at the plants. No sludge is wasted at either plant.

Some conditions that could cause upsets to the biological treatment system are as follows:

- Low phosphate residual level due to pump malfunction, inadequate amount of phosphoric acid added, or frozen lines.

- Excessively high ammonia concentrations into the system because of a breakdown in the ammonia still.

- Loss of dilution water. This could result from pump malfunction or from experimenting in optimizing the amount of dilution water.

- Change in temperature above or below optimum range due to fouling or breakdown of heat exchangers.

- Loss of an aerator. If prolonged, this can cause bugs to die as a result of low dissolved oxygen. This also causes the water temperature to rise, as the aerators provide cooling.

Effective O&M practices at the plants have minimized the potential of upsets; e.g., frequent checks on phosphate residual, good communications between ammonia still operator and treatment plant operator, constant checks on temperature, and monitoring of aerator performance.

SELF-MONITORING DATA

Another aspect of the study included analysis of self-monitoring data for NPDES permits. Data were collected on approximately 35 steel mills, an average of roughly two years of data at each mill. The excursions and reported causes were usually in letter form, which had to be reduced to summary quantitative form. Figure 7 shows the frequency of upsets by pollutant. The data show that the three most troublesome excursions involve oil, solids, and pH. This is at least partially attributable to the fact that they are the most commonly monitored. The qualitative reasons for excursions were categorized based on judgment selections of a reasonable number of categories. The resultant data are shown in Table 3. The most frequently cited causes are generally categorized as leaks, housekeeping, and operator error. We hope to subdivide this category further into more specific causes later in the project.

Our evaluations of self-monitoring data have led us to conclude that plants freely report excursions, causes are often not known or reported, frequency of excursions exceeds that contemplated by guidelines, inadequate design is rarely cited as a cause, and there is no single dominant cause for excursions.

Nonrepresentative sampling is given as a cause for permit excursions in 15 percent of the cases examined from noncompliance data at state offices.

TABLE 3. REPEATED CAUSES OF EXCURSIONS, BASED ON SELF-MONITORING DATA

	Percent
Leaks/housekeeping/operator error	35
Non-representative sampling	15
Equipment malfunction	11
Maintenance/shutdown	10
Hydraulic overload (mostly rain)	6
pH/polymer control	4
Freezing conditions	4
Sludge dewatering/handling	3
Process variation	3
Design	1
Other	8

This includes samples taken at the wrong location, contaminated samples, and inadequate or faulty analytical methods. Although this is the second highest cause of excursions in the self-monitoring data, none of the plants visited cited any of the above factors as a major problem.

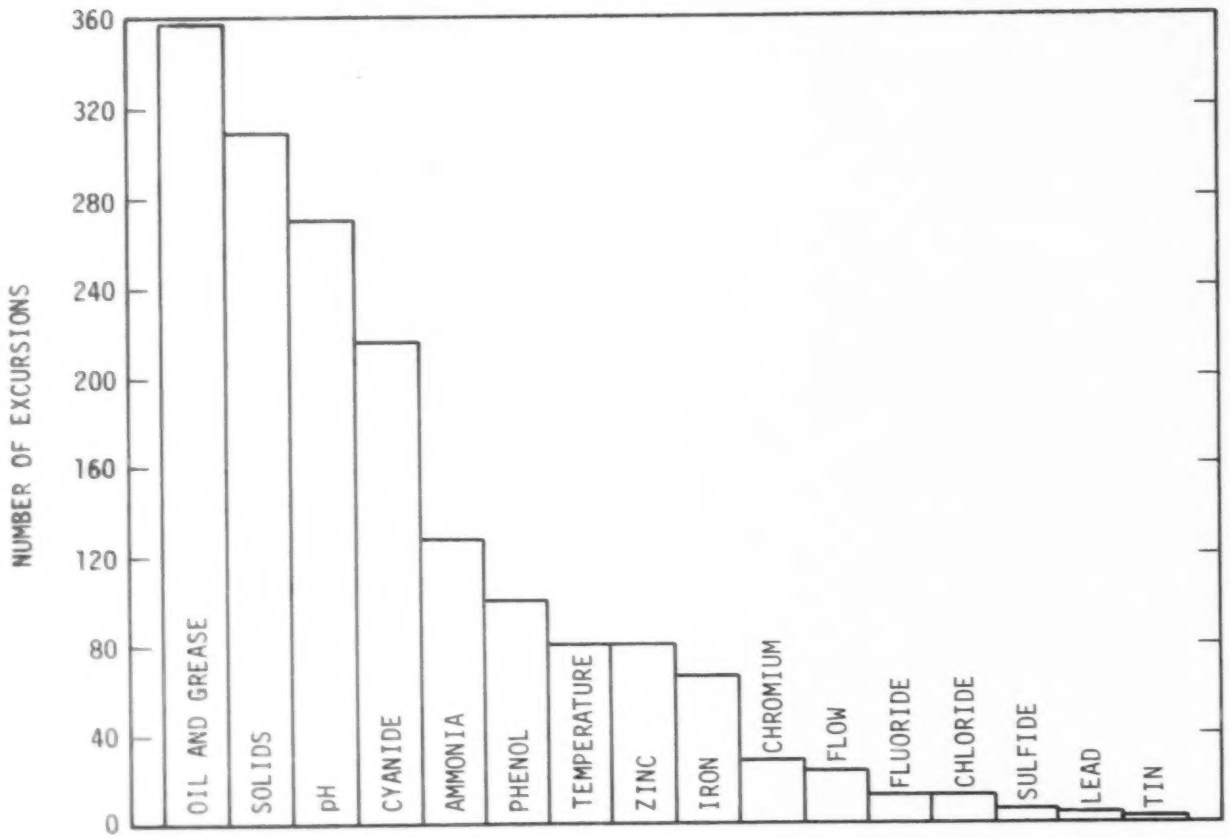


Figure 7. Frequency of excursions, by pollutant, based on self-monitoring data.

SAMPLING AND MONITORING

Measurement of flow and maintenance of automatic samples, although traditional problems in the wastewater field, were not cited by the plants as a major area of concern. Flow monitoring is generally not accurate, however. At one plant, none of three relatively new flow meters was working, but this was an exception.

In general, the operation and maintenance of the treatment system take place at one level and the NPDES monitoring and reporting take place at an entirely different level, with very limited interaction. In most cases, the operators have developed their own sampling and monitoring programs and key indicators for their own use in running the plant. The actual outfall monitoring and permit matters, however, are conducted by the environmental department. The two activities go on rather independently, and it is difficult to relate O&M practices quantitatively to permit upsets.

The high maintenance requirements of pH probes and on-line analytical monitors seem to be universal. Some plants use frequent (once or more per shift) grab measurements of pH and do not really rely on the pH instrumentation. Some attempt is made to maintain, clean, and repair pH probes on a frequent basis (once/2 weeks), but this is a continuing battle. At one installation, two pH probes are used and an alarm is activated based on a differential signal. The probes are then examined to determine which is faulty.

On-line analyzers, such as those for ammonia, cyanide, and oxygen reduction potential (ORP), suffer the same shortcomings as the pH systems. Most were not working, probably because they are such a high maintenance item and the plants seem to meet permit conditions without them.

Bubbler tubes for level control are used in many locations and apparently work well with little maintenance.

In general, it appears that sophisticated monitoring and instrumentation equipment does not work reliably without unrealistically high maintenance requirements. On the other hand, most plants have found simple reliable monitoring techniques that enable them to meet their permit conditions without relying on the sophisticated instrumentation.

CONCLUSIONS

The general highlights of the plants visited to date are the high degree of operator know-how and job interest, the high degree of system monitoring to maintain performance, apparent concern and interest in pollution control, good attention to visual inspections, well-staffed departments, and cooperative attitude and willingness to share information.

The general areas of concern are lack of communication between process operators and water treatment operators; competition between treatment plant and production process for maintenance resources; performance of pH monitoring, on-line analyzers, and flow measurement devices; hydraulic balance; excessive oil from rolling mills; high maintenance required on lime-based ammonia stills; debris in clarifiers/tanks/open-top containers; and lack of detailed maintenance records.

This report will produce more conclusions and data as it continues for another two months and one or two more plant visits are made. All of the current information plus the newly collected data will be evaluated and included in a final report at the end of January.

ACKNOWLEDGMENTS

Without identifying plant names, as was agreed upon from the onset, the authors would like to express their sincere appreciation to the corporations that participated in this study. All have been very cooperative in providing up to a week of time and usually involving several people. The collected information is invaluable to the success of the project and will be used to generate a final report intended to benefit both plant and agency personnel.

APPENDIX

Attendees

EPA Form 2350-4 (4-80)
(PREVIOUSLY CIN. EPA FORM 287)
TYPING GUIDE SHEET

Alford	Michael R.	401 M Street, S.W. (PM-219)	Washington	DC	20460	U.S. EPA
Amendola	Gary A.	25089 Center Ridge Road	Westlake	OH	44145	U.S. EPA
Annamraju	Gopal	11499 Chester Road	Cincinnati	OH	45246	PEDCo Environmental, Inc.
Arnold	David L.	6th and Walnut Streets	Philadelphia	PA	19106	U.S. EPA, Region III
Aronds	Cornelis A.	Postbus 10000	1970 CA IJmuiden	NETHERLANDS		Estel Hoogovens BV
Askins	Charles W.	P. O. Box 401	Beaver Falls	PA	15010	Babcock & Wilcox
Ayer	Franklin A.	P. O. Box 12194	Research Triangle Park	NC	27709	Research Triangle Institute
Banninthaya	K. Shankar	301 39th Street, APC	Pittsburgh	PA	15201	Allegheny County Health Department
Baskerville	Jesse	345 Courtland St., N.E.	Atlanta	GA	30365	U.S. EPA, Region IV
Beck	Leslie L.	OAQPS, MD-13	Research Triangle Park	NC	27711	U.S. EPA
Bedick	Robert C.	2400 Ardmore Boulevard	Pittsburgh	PA	15230	Energy Impact Associates
Boltz	David G.	Room B-252, Martin Tower	Bethlehem	PA	18016	Bethlehem Steel Corporation
Booth	Roger	100 King Street, W.	Hamilton, Ontario	CANADA	L8N 3T1	Stelco, Inc.
Brady	Dennis	S-3556 Lake Shore Road	Buffalo	NY	14219	Bethlehem Steel Corporation
Brand	Peter	21 St. Clair Avenue East	Toronto, Ontario	CANADA	M4T 1L9	Hatch Associates, Ltd.
Browne	Nick	135 Cumberland Road	Pittsburgh	PA	15237	Bischoff Environmental Systems
Buchko	Nicholas S.	200 Neville Road	Pittsburgh	PA	15225	Shenango, Inc.
Caine, Jr.	John C.	600 Grant Street	Pittsburgh	PA	15219	Wheelabrator-Frye
Cairns	D. F.	7777 Bonhomme Avenue	St. Louis	MO	63105	National Engineers and Associates
Cappannari	Charles	MS-59, Homestead Works	Homestead	PA	15120	U.S. Steel Corporation
Caruso	S. Charles	4400 Fifth Avenue	Pittsburgh	PA	15213	Mellon Institute
Cerny	Rodney A.	One Erieview Plaza	Cleveland	OH	44114	The H. K. Ferguson Company
Chabala	David M.	650 Washington Road	Pittsburgh	PA	15228	Cyclops Corporation
Chappell	Jeff	IERL, MD-63	Research Triangle Park	NC	27711	U.S. EPA
Cherryholmes	Keith L.	12161 Lackland Road	St. Louis	MO	63141	Envirodyne Engineers, Inc.
Chleboski	Ronald J.	301 39th Street, APC	Pittsburgh	PA	15201	Allegheny County Health Department
Conner	Jesse R.	5371 Cook Rd., P. O. Box 888	Morrow	GA	30260	SolidTek, Inc.
Conners	Alan	32nd Street and AVRR	Pittsburgh	PA	15201	Pennsylvania Engineering Corporation
Cooper	Leah A.	Highway 259 South	Lone Star	TX	75668	Lone Star Steel Company
Craig	Richard	26 Federal Plaza	New York	NY	10278	U.S. EPA, Region II
Crist	Joseph G.	125 Jamison Lane	Monroeville	PA	15146	U.S. Steel Corporation
Crocker	John C.	1201 Elm Street, Suite 2800	Dallas	TX	75220	U.S. EPA, Region VI
Cronin	D. R.	600 Grant St.	Pittsburgh	PA	15230	U.S. Steel Corporation
Cusano	Virginia M.	P. O. Box 977	Syracuse	NY	13201	Crucible, Inc.
Cuscino, Jr.	Thomas	425 Volker Boulevard	Kansas City	MO	64110	Midwest Research Institute
Daly	Edwin R.	152 Floral Avenue	Murray Hill	NJ	07974	Krupp Wilputte Corporation
de Filippi	Richard P.	25 Acorn Park	Cambridge	MA	02140	Critical Fluid Systems, Inc.
de Jonge	Lex	Zijlweg 245	2015 CL Haarlem	NETHERLANDS		Prov. Dept. of Public Work and Water
DeCoursey, III	Paul J.	4301 Dutch Ridge Road, P. O. Box 280	Beaver	PA	15009	Michael Baker, Jr., Inc.
DeQuittner	Anthony T.	314 Pleasant Avenue	McMurray	PA	15317	ATD Consultants
Dougherty	James H.	Weston Way	West Chester	PA	19380	Roy F. Weston, Inc.
Dropcho	J.	One Oliver Plaza	Pittsburgh	PA	15222	Dravo Corp.
Eastman	Douglas K.	P. O. Box 460	Hamilton, Ontario	CANADA	L9H 3V2	Dofasco, Inc.
Edmonds	Peter R.	P. O. Box 71	Murrysville	PA	15668	Energy & Environmental Management, Inc.
Emerson	Lynn R.	P. O. Box 1346	Pittsburgh	PA	15230	Calgon Corporation
Fabian	Terry R.	Rm 850 Kossman Bldg., 100 Forbes Ave.	Pittsburgh	PA	15222	PA Dept. of Environmental Resources
Falvey	Patrick C.	Park West II, Cliff Mine Road	Pittsburgh	PA	15275	NUS Corporation
Farley	G. Dale	1553 Washington St., E.	Charleston	WV	25311	WV Air Pollution Control Commission
Feigenbaum	Simon	301 39th Street, APC	Pittsburgh	PA	15201	Allegheny County Health Department
Felt	Robert L.	301 39th Street, APC, Building 7	Pittsburgh	PA	15201	Allegheny County Health Department
Fenton	George P.	904 Mt. Royal Boulevard	Pittsburgh	PA	15223	Busch Co.
Fitzpatrick	Marjorie J.	550 Pinetown Road	Fort Washington	PA	19034	JACA Corp.
Ford	Joseph R.	P. O. Box 401	Beaver Falls	PA	15010	Babcock & Wilcox
Forrelli	James R.	5777 Baum Boulevard	Pittsburgh	PA	15206	Betz Converse Murdoch, Inc.
Francis	Steve	1808 Crawford Street	Middletown	OH	45043	Armco Inc.
Fullerton	R. W.	125 Jamison Lane	Monroeville	PA	15146	U.S. Steel Corporation
Geddis	Robert	3923 Ensign Court	Atlanta	GA	30341	Air Pollution Regulatory Services, Inc.
Gleason	William L.	Koppers Building	Pittsburgh	PA	15219	Koppers Co., Inc.
Goldburg	Walter I.	1237 Murdoch Road	Pittsburgh	PA	15217	Group Against Smog and Pollution

Greenfield	Jeffrey H.	School of Engineering	Pittsburgh	PA	15261	University of Pittsburgh
Greenfield	Murray S.	P. O. Box 460	Hamilton, Ontario	CANADA	L8N 3J5	Dofasco, Inc.
Groves	Kenneth O.	2020 Dow Center	Midland	MI	48640	Dow Chemical U.S.A.
Hagarman	James A.	1020 Seventh North Street	Liverpool	NY	13088	Calocerinos & Spina
Halapin	Andrew M.	904 Mt. Royal Boulevard	Pittsburgh	PA	15223	Busch Co.
Hall	John D.		Ecorse	MI	48229	Great Lakes Steel
Hancock	Nona L.	7777 Bonhomme Avenue	St. Louis	MO	63105	National Engineers and Associates
Hansen	Penelope	401 M Street, S.W. (WH-565A)	Washington	DC	20460	U.S. EPA
Harshman	Robert	504 Beaver Street	Sewickley	PA	15143	Green International, Inc.
Hart	Fred C.	530 Fifth Avenue	New York	NY	10036	Fred C. Hart Associates, Inc.
Haskill	Jim	Water Pollution Control Directorate	Ottawa, Ontario	CANADA	K1A 1C8	Environment Canada
Hawthorne	J. O.	125 Jamison Lane	Monroeville	PA	15146	U.S. Steel Corporation
Heijwegen	C. P.	Postbus 10000	1970 CA IJmuiden	NETHERLANDS		Estel Hoogovens BV
Hinrichs	Hans-Friedrich	Triererstrasse 1	6600 Saarbrucken	W GERMANY		Saarbergwerke AG
Hoffman	C. F.	125 Jamison Lane	Monroeville	PA	15146	U.S. Steel Corporation
Hoffman	Thomas W.	One NCNB Plaza, 38th Floor	Charlotte	NC	28280	Midrex Corporation
Hosking	Richard W.	1500 Oliver Building	Pittsburgh	PA	15228	Kirkpatrick-Lockhart-Johnson-Hutchison
Hudiburgh	Gary	401 M Street, S.W. (EN-336)	Washington	DC	20460	U.S. EPA
Hughes	James J.	1000 16th Street, N.W.	Washington	DC	20036	American Iron and Steel Institute
Hupe	David	4301 Dutch Ridge Road, P. O. Box 280	Beaver	PA	15009	Michael Baker, Jr., Inc.
Jasinski	Michael	213 Burlington Road	Bedford	MA	01730	GCA Corporation/Technology Division
Jeffery	John D.	213 Burlington Road	Bedford	MA	01730	GCA Corporation/Technology Division
Jenkins	Cate	401 M Street, S.W.	Washington	DC	20460	U.S. EPA
Junkins	Randy	Weston Way	West Chester	PA	19380	Roy F. Weston, Inc.
Kawaters	Woody	800 Connecticut Blvd.	East Hartford	CT	06108	TRC Environmental Consultants, Inc.
Keffer	Ron E.	440 College Park Drive	Monroeville	PA	15146	Koppers Company, Inc.
Kelleher	Maria	33 Yonge Street	Toronto, Ontario	CANADA	M5E 1E7	MacLaren Engineers
Kemner	William	11499 Chester Road	Cincinnati	OH	45246	PEDCo Environmental, Inc.
Kerecz	B.	Homer Research Labs	Bethlehem	PA	18016	Bethlehem Steel Corporation
Kesari	Laxmi N.	401 M Street, S.W.	Washington	DC	22091	U.S. EPA
Klippel	Richard W.	1020 Seventh North Street	Liverpool	NY	13088	Calocerinos & Spina
Kozy	Michael J.	One Oliver Plaza	Pittsburgh	PA	15222	Dravo Corp.
Krishnan	E. Radha	11499 Chester Road	Cincinnati	OH	45246	PEDCo Environmental, Inc.
Krupinski	Kenneth	125 Jamison Lane, MS-57	Monroeville	PA	15146	U.S. Steel Corporation
Krzymowski	Cezary	1701 First Avenue, DAPC	Maywood	IL	60153	Illinois EPA
Kunz	Joseph W.	6th and Walnut Streets	Philadelphia	PA	19106	U.S. EPA, Region III
Lace, Sr.	Robert H.	P. O. Box 6428	Ft. Myers	FL	33911	The Munters Corporation
Laskowski	Stanley	Curtis Bldg., 6th and Walnut Streets	Philadelphia	PA	19106	U.S. EPA, Region III
Lennon	Joseph F.	One Parklane Blvd., 628 Parklane W.	Dearborn	MI	48126	Ford Motor Company
Lin	Eddy	465 Fullerton	Elmhurst	IL	60126	Pacific Environmental Services, Inc.
Lucas	Joseph H.	4400 Fifth Avenue	Pittsburgh	PA	15213	Mellon Institute
MacDowell	William L.	230 S. Dearborn	Chicago	IL	60604	U.S. EPA, Region V
Mahar	Kevin D.	47 Evanston Pl.	Buffalo	NY	14220	B. K. K. Consulting, Inc.
Maser	Joseph	P. O. Box 71	Murrysville	PA	15668	Energy & Environmental Management, Inc.
Masters	Richard W.	600 Grant Street	Pittsburgh	PA	15230	U.S. Steel Corporation
Matuza	M. Raymond	#4, 33 Milford Road	Hudson	OH	44236	Betz Laboratories, Inc.
Maze	Jeffrey	1400 Lee Drive	Coraopolis	PA	15108	Calocerinos & Spina
McCrillis	Robert C.	IERL, MD-63	Research Triangle Park	NC	27711	U.S. EPA
McDermott	James E.	230 S. Dearborn	Chicago	IL	60604	U.S. EPA, Region V
Mears	Connally E.	1860 Lincoln Street (8AW-AP)	Denver	CO	80295	U.S. EPA, Region VIII
Melcer	Henryk	P. O. Box 5050, Wastewater Tech. Ctr.	Burlington, Ontario	CANADA	27R 4A6	Environment Canada
Merritt	John E.	1406 Chamber of Commerce Building	Pittsburgh	PA	15219	Koppers Co., Inc.
Metzger	Daniel J.	7777 Bonhomme Avenue	St. Louis	MO	63105	National Engineers and Associates
Mihelic	E. L.	125 Jamison Lane	Monroeville	PA	15146	U.S. Steel Corporation
Miller	A. Leslie	Koppers Building	Pittsburgh	PA	15219	Koppers Co., Inc.
Mohiuddin	Jaffer	8230 Boone Boulevard, Suite 450	Vienna	VA	22180	Pacific Environmental Services, Inc.
Mura	William R.	2800 Grant Building	Pittsburgh	PA	15219	National Steel Corporation
Murphy	Samuel M.	Ft. Boone Plaza, 18 Reilly Road	Frankfort	KY	40601	KY Dept. of Environmental Protection
Murray	Daniel J.	25089 Center Ridge Road	Westlake	OH	44145	U.S. EPA

Nelson, Jr.	Theodore W.	223 W. Jackson Boulevard	Chicago	IL	60606	Peter F. Loftus Corporation (Illinois)
Nemeth	Richard L.	3100 East 45th Street	Cleveland	OH	44127	Republic Steel Corporation
Neufeld	Ronald D.	Department of Civil Engineering	Pittsburgh	PA	15261	University of Pittsburgh
Neufeld	Walter	1000 16th Street, N.W.	Washington	DC	20036	American Iron and Steel Institute
Nicola	Arthur G.	32nd Street and AVRR	Pittsburgh	PA	15201	Pennsylvania Engineering Corporation
Nixon	Pauline	209 South Braddock Avenue #2	Pittsburgh	PA	15221	University of Pittsburgh
Norton	Colburn L.	P. O. Box 71	Murrysville	PA	15668	Energy & Environmental Management, Inc.
Nutt	Stephen G.	178 Louisa Street	Kitchener, Ontario	CANADA	N2H 5M5	Canviro Consultants, Ltd.
O'Barsky	Bernie	2800 Grant Building	Pittsburgh	PA	15219	National Steel Corporation
Obenchain	W. A.	1740 N. Highland Road	Pittsburgh	PA	15241	Obenchain Corp.
Oda	Terry N.	6th and Walnut Streets	Philadelphia	PA	19106	U.S. EPA, Region III
Olthof	M.	3185 Babcock Boulevard	Pittsburgh	PA	15237	Duncan, Lagnese & Associates
Pajak	Andrew P.	4301 Dutch Ridge Road, P. O. Box 280	Beaver	PA	15009	Michael Baker, Jr., Inc.
Paquette	Steve	Park West II, Cliff Mine Road	Pittsburgh	PA	15228	NUS Corporation
Pashel	George	Room B-252, Martin Tower	Bethlehem	PA	18016	Bethlehem Steel Corporation
Patterson	James W.	IIT Center	Chicago	IL	60616	Illinois Institute of Technology
Pedersen	Stephen F.	600 Kossman Bldg., 100 Forbes Ave.	Pittsburgh	PA	15222	PA Dept. of Environmental Resources
Pennell	Earl R.	Council Avenue	Wheatland	PA	16161	Wheatland Tube Co.
Peters	Michael S.	P. O. Box 911	Seguin	TX	78155	Structural Metals, Inc.
Price	Richard T.	11499 Chester Road	Cincinnati	OH	45246	PEDCo Environmental, Inc.
Prizinsky	David	1006 Empire Building	Pittsburgh	PA	15222	American Metal Market
Procyk	B. A.	125 Jamison Lane	Monroeville	PA	15146	U.S. Steel Corporation
Quigley	Joe	P. O. Box 266	Duquesne	PA	15110	CAMETCO, Inc.
Radigan	Patrick	2800 Grant Building	Pittsburgh	PA	15219	National Steel Corporation
Reed	Jerome G.	710 Washington Plaza	Pittsburgh	PA	15219	Engineering News Report
Reggi	John	1911 Warwood Avenue	Wheeling	WV	26003	WV Air Pollution Control Commission
Rugge	Hooite	P. O. Box 217	Fontana	CA	92335	Kaiser Steel Corporation
Ruppersberger	John S.	IERL, MD-63	Research Triangle Park	NC	27711	U.S. EPA
Sable	Ellen R.	Shenley Park	Pittsburgh	PA	15213	Carnegie-Mellon University
Sawchuck	Peter W.	440 College Park Drive	Monroeville	PA	15146	Koppers Company, Inc.
Schlosser	Robert	550 Pinetown Road	Fort Washington	PA	19034	JACA Corp.
Schuldt	A.	100 King Street, W.	Hamilton, Ontario	CANADA	L8N 3T1	Stelco Inc.
Schwartz	Stephen M.	1000 16th Street, N.W.	Washington	DC	20036	American Iron & Steel Institute
Sebastian	Frank	One Penn Plaza	New York	NY	10119	Envirotech
Shaughnessy	John P.	10 Chatham Road	Summit	NJ	07901	MikroPul Corporation
Simmons	Donald W.	2800 Grant Building	Pittsburgh	PA	15219	National Steel Corporation
Simmons	Larry L.	P. O. Box 71	Murrysville	PA	15668	Energy & Environmental Management, Inc.
Skicki	Anthony M.	P. O. Box 2063, Water Quality Mgmt.	Harrisburg	PA	17120	PA Dept. of Environmental Resources
Smith	John R.	440 College Park Drive	Monroeville	PA	15146	Koppers Company, Inc.
Spawn	Peter D.	213 Burlington Road	Bedford	MA	01730	GCA Corporation/Technology Division
Spinola	Anthony A.	600 Grant Street	Pittsburgh	PA	15235	U.S. Steel Corporation
Splitstone	D. E.	125 Jamison Lane	Monroeville	PA	15146	U.S. Steel Corporation
Stasiak	Edward	3426 E. 89th Street	Chicago	IL	60617	U.S. Steel Corporation
Stein	Robert M.	P. O. Box 40284	Nashville	TN	37204	AWARE, Inc.
Steiner	Bruce A.	P. O. Box 600	Middletown	OH	45043	Armco Inc.
Stern	Richard D.	IERL, MD-63	Research Triangle Park	NC	27711	U.S. EPA
Sterner	Charles J.	Martin Tower	Bethlehem	PA	18016	Bethlehem Steel Corporation
Stouch	Jim	355 Fifth Avenue	Pittsburgh	PA	15222	Raymond Kaiser Engineers, Inc.
Tarbert	R. E.	125 Jamison Lane	Monroeville	PA	15146	U.S. Steel Corporation
Telford	Anton	2200 Churchill Road	Springfield	IL	62706	Illinois EPA
Thompson	Regina C.	6th and Walnut Streets (3AW21)	Philadelphia	PA	19106	U.S. EPA, Region III
Touhill	C. Joseph	4301 Dutch Ridge Road, P. O. Box 280	Beaver	PA	15009	Michael Baker, Jr., Inc.
Traina	V. P.	2130 West Park Drive	Lorain	OH	44053	R. E. Warner and Associates
Trembly	Martin G.	25089 Center Ridge Road	Westlake	OH	44145	U.S. EPA
Tuckey	J. D.	Technology Department	Sparrows Point	MD	21219	Bethlehem Steel Corporation
Vajda	Stephen	900 Agnew Road	Pittsburgh	PA	15227	Jones & Laughlin Steel Corporation
Waechter	Ralph W.	600 Kossman Bldg., 100 Forbes Ave.	Pittsburgh	PA	15222	PA Dept. of Environmental Resources
Wallace	Anna W.	P. O. Box 12194	Research Triangle Park	NC	27709	Research Triangle Institute
Wesson	Sheldon	1000 16th Street, N.W.	Washington	DC	20036	American Iron and Steel Institute

West	William L.	P. O. Box 6778, Room 520-R	Cleveland	OH	44101	Republic Steel Corporation
Westman	Roger C.	301 39th Street, APC	Pittsburgh	PA	15201	Allegheny County Health Department
Wills, Jr.	Robert H.	P. O. Box 977	Syracuse	NY	13201	Crucible, Inc.
Wilson	W.	Aliquippa Works, P. O. Box 490	Aliquippa	PA	15001	Jones & Laughlin Steel Corporation
Wilson, Jr.	Leon W.	125 Jamison Lane	Monroeville	PA	15146	U.S. Steel Corporation
Wisniewski	L. D.	P. O. Box 6778, Env. Control Dept.	Cleveland	OH	44101	Republic Steel Corporation
Workman	W. S.	125 Jamison Lane	Monroeville	PA	15146	U.S. Steel Corporation
Young, Jr.	Earle F.	1000 16th Street, N.W.	Washington	DC	20036	American Iron & Steel Institute
Zwikl	James R.	200 Neville Road	Pittsburgh	PA	15225	Shenango, Inc.